ANNALS

OF THE

Association of American Geographers

VOLUME XV SEPTEMBER 1925 No. 3

SPECIAL MAPS FOR CHARTING STORM MOVEMENTS*

BY ALEXANDER McADIE

Some thirty-five years ago my predecessor, the late Professor A. Lawrence Rotch, succeeded in having the Signal Service authorities consent to publish a local daily weather map. While others claim credit for the inauguration of the map at the Boston Office, which was the first map of its kind ever published in the United States, I find that Mr. Rotch, initiated the work, was allowed to pay the bill, and is entitled to whatever credit there may be for the innovation.

The issue of a daily weather map at the more prominent Weather Bureau stations, was a great step forward in educating the public regarding the fundamentals of aerography. The question naturally arises, Has all been done that might be done in this direction? Apparently there have been no noteworthy changes either in material used or in the methods of presentation.

This paper then naturally has to consider first the map itself and second the material that should be presented in order that students of aerography (and for that matter all mankind) should gain as much knowledge as possible regarding the structure of the atmosphere in general and the sequence of weather changes in particular.

First as to the map itself. The map now issued is 28 centimeters by 40 centimeters. The upper half of the sheet contains a map without relief and the lower half contains printed text and tables of observations at a given moment, 8 A. M., 75th Meridian Time.

Making use of the chalk plate process, lines of equal pressure are drawn as full lines and isotherms as dotted lines. In the lower left hand corner a space about 32 square centimeters is devoted to explanatory notes In the lower right hand corner, a space of about 20 square centimeters is occupied by wind barometer indications. A space of about 5 square centimeters contains a scale of statute miles which is a step backward, because if only one scale of distances is to be used, it

*Read before Association of American Geographers, Washington, D.C., Jan. 1, 1925.

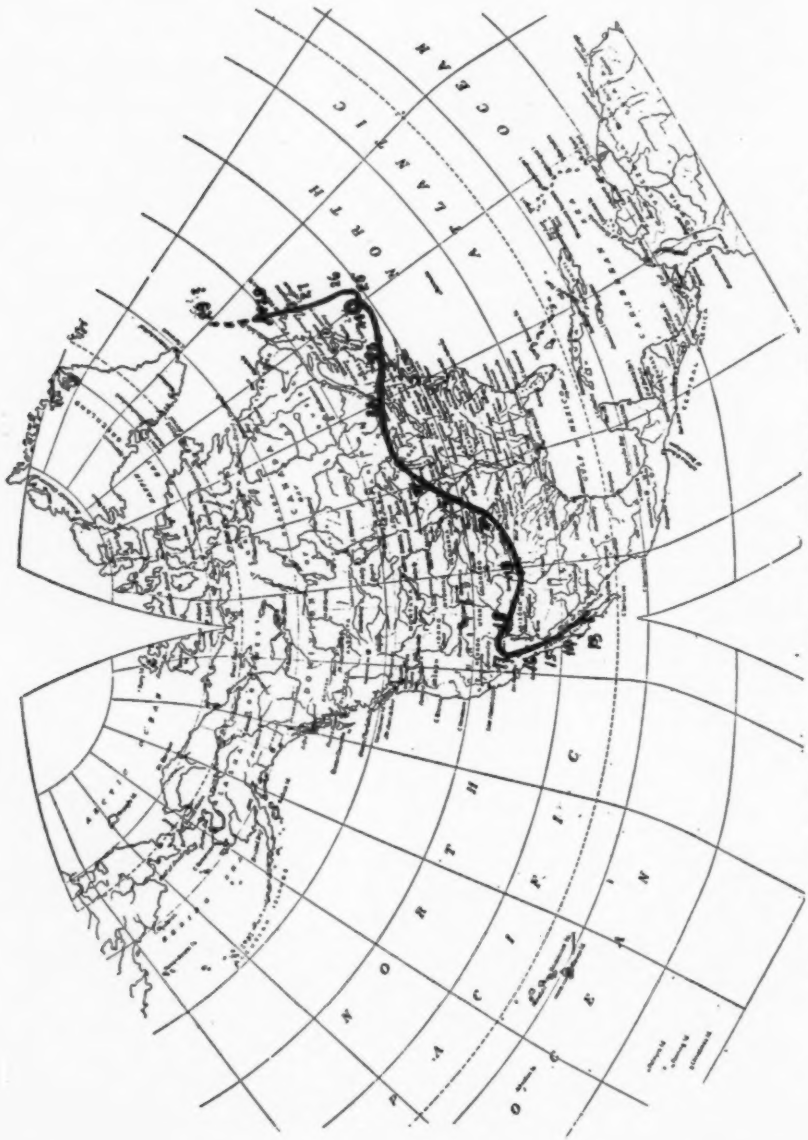


Fig. 1. Track of a Storm (Apr. 13-27, 1923) on Cahill's Projection ("The Butterfly Map.")

should be kilometers. If the people of the United States are not now after the experience of a great war and years of use of radio wave lengths familiar with the kilometer, it is high time they were shaken out of their indifference. The map in question is officially known as Map DD.

It seems to us that it would be an improvement to use the map given in the Monthly Weather Review on which isobars at sealevel and isotherms at the surface, are charted. This map gives the relief or topographic features of the country; and in our opinion a constant remembrance of these features is important is comprehending the distribution of rain, the flow of air, and the control of temperature. On this map the scale of 1:12200000 is given and the distances in kilometers and statute miles. But on this map, as on the Daily Weather Map, isotherms are uncorrected for either time or elevation. A temperature of 10° F. at Winnemucca at 5 o'clock in the morning is given the same value and so expressed on the map as a reading made at 9 o'clock at Halifax. The isobars are reduced to sealevel but also lack correction for time. Thus the isobar and the isotherm do not really represent conditions at 8 A. M. local time, and there can be no true comparison. The map should be, if possible, an equal area map. The use of a Mercator projection gives large distortion in the very regions where exactness is most needed. The paths and movements of storms are magnified and unless guarded against lead to wrong impressions. As large an area as possible should be covered; but both on the Atlantic coast and on the Pacific it is of some importance to have available for charting a fairly large area of adjacent ocean, for more and more forecasters at coast stations realize how important it is to have full reports from the sea. In this respect the present map might well be improved. Maps issued at New York, Boston, New Orleans, San Francisco, and Seattle need ample sea-room. The old excuse that no reports could be had in time for charting from ships at sea no longer holds. In the case of Boston for example it is all important to know if a disturbance which has apparently passed to sea continues its east movement or is blockaded. A storm which worked havoc with the forecasts is shown charted herewith on two different projections, both of which seem to be preferable to the present DD map. This is the disturbance of April 13-27, 1923, a remarkable storm. The first map (Fig. 1) shows half of the Northern Hemisphere, a projection by Mr. B. J. S. Cahill of Oakland, Cal., the well-known Butterfly Map, an equal area map with rectified meridians. This map has many advantages and is excellent for lantern slides. The other map (Fig. 2) is a portion of the circumpolar map

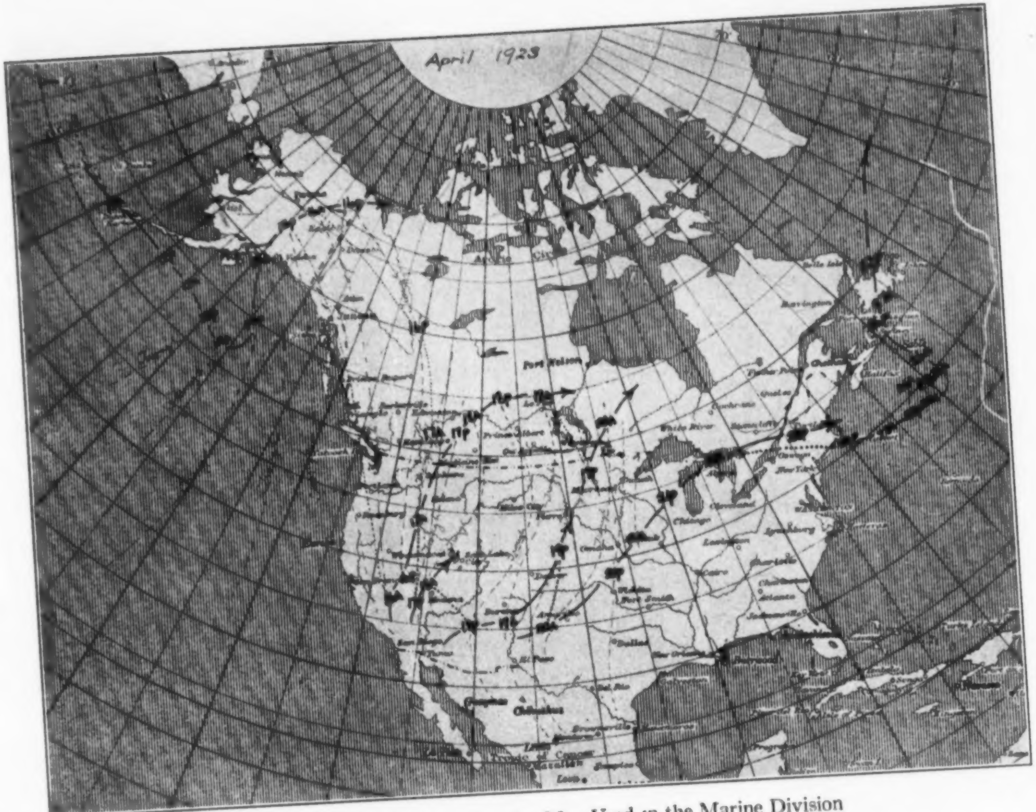


Fig. 2. Part of Circumpolar Map Used in the Marine Division

used in the Marine Division and also has many advantages. The storm tracks on this map were kindly drawn for me by the officials of the Weather Bureau.

Regarding the data that should be presented, opinions will differ and what suits the public may not satisfy the needs of the student of aerography; but it may be possible to serve both interests better than is now the case. It will no doubt seem like striking at the root of things; but the writer believes that neither isobars nor isotherms should appear on the map. It sounds radical, but all these could be given in tabular shape in the text below. If indeed they are really wanted! Air pressure initiates air motion, and when we chart isobar and wind-direction we virtually duplicate data. And instead of surface winds, the so-called geostrophic winds, which can easily be obtained by nephoscopic observation of the lower clouds (1000 to 1500 metres) should be given, with length of arrow indicating velocity and barbs indicating duration in time units. It is important to know whether the flow is steady or about to shift. If pressure must be given, let it be in percentage or permillage departures from a standard pressure for that locality. This is an improved isallobar; and is very important in connection with the steering line of the storm. Finally some indication of the type of structure prevailing should be shown.

MEAN SEA LEVEL AND ITS VARIATIONS*

BY H. A. MARMER

Sea level is the universal datum to which heights on land and depths in the sea are referred. Its universal use as a datum plane is due to a number of advantages it possesses. It is a rational datum plane and one that everywhere has the same definition; it is, too, a familiar term and one that is self-explanatory. Where considerable heights or depths are involved an approximate determination of sea level is frequently all that is required, and approximately, sea level is very easily determined; for, excepting localities of large tides, the level of the sea at any instant may be taken as a first approximation to sea level. A better approximation, which is applicable even in regions of large tides, is derived by taking sea level half way between a high water and a succeeding or preceding low water.

The geographer and geologist have adopted the term and by prefixing the word "mean" have sought to give it a more precise meaning. "Mean sea level" is apparently free from ambiguity and carries an implication that apart from the effects of storms, it is a plane that can be determined readily and accurately. However, when it becomes necessary to determine this plane accurately, as for example, in the study of the subsidence or emergence of a coast or in the establishment of primary bench marks in a precise leveling scheme, difficulties appear.

GEODETIC VS. GEOGRAPHIC MEAN SEA LEVEL.—Before discussing the determination of mean sea level it will be of advantage to define precisely just what is meant by mean sea level. The level of the sea is at all times disturbed by wind and weather and tide. Is mean sea level therefore to be defined as the surface the sea would assume if undisturbed by weather and tide? Such a definition is quite legitimate, and is the one the geodesist prefers. To quote his own words, "mean sea level may be defined as the surface which would coincide with the surface of the oceans and their tide water branches, if the tide producing force should cease to act and there were no movements of the air and the barometric pressure were uniform."[1]

It is to be observed, however, that notwithstanding the advantages of the geodesist's mean sea level is his own work, it is in a sense a hypothetical surface; for while the effects of the rise and fall of the tide on sea

*Read before Association of American Geographers, Washington, D.C., Jan. 1, 1925.

[1] William Bowie: Present Status of Geodesy and Some of the Problems of this Branch of Geophysics. *Proc. Nat. Acad. of Sciences*, Vol. 6, 1920, p. 548.

level balance out if the observations are continued over a considerable period of time, the effects of air movements and of variations in barometric pressure do not balance out, but leave a resultant effect. Considerable work has been done in deriving methods for eliminating the resultant meteorological effects from sea level, but a great deal still remains to be done.

For geographic and geologic purposes some of the difficulties inherent in geodetic sea level may be overcome by defining mean sea level differently. With regard to any particular point on the coast, mean sea level may be defined as the average level of the sea, or as the plane about which the tide oscillates. In contradistinction to geodetic sea level, this plane may be called local sea level, or better, geographic sea level. The advantage of this plane of geographic mean sea level is that it may be determined directly from observations. For all that need be done is to measure the height of the tide at frequent intervals, the average of these heights over a considerable period of time being the geographic mean sea level. It is the geographic mean sea level with which this paper is concerned, and when the term mean sea level is used here, geographic mean sea level will be understood.

Strictly, geodetic mean sea level is a surface which must be determined with reference to mean sea level at a given initial point. At this point geodetic and geographic mean sea level coincide. But at some distance from this initial point the two surfaces begin diverging, due to the resultant effects of meteorological factors which are reflected in geographic mean sea level, but from which geodetic mean sea level is free. Thus, recent precise leveling by the Coast and Geodetic Survey between New York City and Portland, Me., brings out the fact that the plane of geographic mean sea level at Portland is about half a foot higher than that at New York City, which means that in the distance of about three hundred miles separating these places geodetic and geographic mean sea level diverge about half a foot. Similarly, precise leveling in Great Britain has shown that from Newlyn on the English Channel to Dunbar on the North Sea—an air-line distance of about four hundred miles, but twice that distance along the coast—geodetic and geographic mean sea level diverge 0.8 foot.[2]

Mean Sea Level and Half Tide Level.—As a precise datum plane mean sea level must be carefully distinguished from half-tide level. Mean sea level is defined as the average level of the sea and is determined by averaging the height of the tide as measured at frequent intervals,

[2] The Second Geodetic Levelling of England and Wales, 1912-1921, London, 1922 p. 34.

generally every hour. Half-tide level is the plane that lies exactly half way between high water and low water and is determined by averaging the heights of the high and low waters only. If the curve representing the rise and fall of the tide were that of a simple sine curve, the planes of mean sea level and half-tide level would coincide. But the tide curve is not a simple sine curve and it is found that the average rise of high water above sea level is not exactly the same as the average fall of low water below sea level.

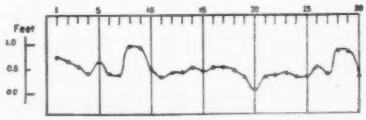
At any point on the open coast the planes of mean sea level and of half-tide level generally differ from each other only by small quantities. And over periods of a year or more the difference between the two planes is so very nearly constant that for most purposes it may be regarded as constant. On the Atlantic coast of the United States the plane of mean sea level lies somewhat above that of half-tide level, the difference between the two being exemplified by 0.03 of a foot at Portland, Me., 0.05 in New York harbor, 0.03 at Atlantic City, N. J., 0.02 at Baltimore, Md., and 0.10 of a foot at Fernandina, Fla. On the Pacific Coast of the United States it is the plane of half-tide level that is the higher, its distance above the plane of mean sea level being 0.05 of a foot at San Diego, Cal., 0.06 in San Francisco Bay, 0.01 at Seattle, Wash., and 0.22 at Anacortes, Wash. Where the difference between the two planes has been determined, either one may be derived from the other; and while they generally differ but little from each other, it is obvious that in any investigation that involves accurate quantitative data the plane of half-tide level cannot be used as synonymous with that of mean sea level.

Variation of Daily Sea Level.—By defining geographic mean sea level at any point as the average level of the sea or as the plane about which the tide oscillates, the determination of mean sea level resolves itself into a problem in the field of tides. The question that arises immediately is, for how long a period must the tide be averaged to secure an accurate determination of mean sea level? This question can perhaps best be answered by a consideration of the results derived from observations of different periods. Since the moon plays the leading rôle in the production of the tides, the average period of the tide or the length of the tidal day is the same as that of the lunar day. This period varies somewhat from one day to another in accordance with the position of the moon relative to the earth and sun, but on the average it is 24 hours and 50 minutes, or approximately one calendar day. Therefore if we measure the height of the tide at frequent intervals during the period of a day and average these heights, the rise and fall of the tide will be

very largely eliminated, the result being a close approximation to sea level.

It is to be noted, however, that the average level of the sea as determined from one day of tidal observations may differ considerably from that of another day because of variations in the meteorological conditions. This is obvious as regards apparent changes in weather, for it is a matter of common knowledge that strong winds or considerable variation in barometric pressure bring about decided changes in the level of the sea. But even with apparently uniform weather conditions sea level exhibits changes from day to day. This is brought out in Figure 1, which shows diagrammatically the changes in height of sea level from day to day at Fort Hamilton in New York Harbor during the month of June, 1919, when weather conditions were relatively uniform. For each day sea level was determined as the average of the twenty-four hourly heights of the tide, which practically eliminated the rise and fall of the tide.

Figure 1 shows changes from day to day in sea level ranging from less than a tenth of a foot to more than half a foot. For the month represented the difference between the highest and lowest daily sea level is 0.9 of a foot. During periods of heavy winds or of considerable changes in barometric pressure the variation in sea level from day to day will obviously be much greater. For example, in February, 1919, four months earlier than the period represented in Figure 1, the difference between the highest and lowest values of sea level at Fort Hamilton was 2.5 feet, while the greatest difference between any two consecutive days was over 1.25 feet.



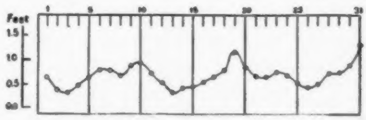


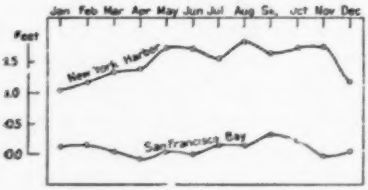
Fig. 1.—Daily Sea Level, Fort Hamilton, N. Y., June 1919.
Fig. 2.—Daily Sea Level, San Francisco, Cal., January 1919..

The variation in sea level from day to day is a characteristic feature not only in New York harbor or along the Atlantic Coast, but of sea level in all arms of the sea and along all coasts. Figure 2 shows the variation in daily sea level during the month of January, 1919, in San Francisco Bay. During this month the wind never attained any considerable velocity, the average wind movement being about five miles per hour, while the greatest wind velocity was twenty-six miles per hour. The greatest difference in daily sea level during the month was exactly one foot, while the greatest difference between any two consecutive days

was 0.4 foot. Here, likewise, had we taken a month during which stronger winds occurred, greater differences in the heights of daily sea level would have been found.

We are, therefore, led to conclude that sea level as determined from one day of tidal observations, even during apparently uniform weather conditions, may vary considerably from that determined on some other day. In part this variation is due to tidal constituents having periods greater than a day and arising from variations in the position of the moon relative to the earth. And in passing it may be noted that since the tidal day is twenty-four hours and fifty minutes in length, a slight variation in sea level is introduced by taking daily sea level as the average of the twenty-four hourly heights of the tide for each calendar day. But this variation, it can be shown, is relatively insignificant, especially in regions of moderate range of tide.

Variation of Monthly Sea Level.—A day is a relatively short period of time and it is not surprising that sea level based on but one day of observations should vary considerably from the mean level of the sea. Suppose, however, we take a month: during this period, surely, we may expect a very close approximation to mean sea level. Let us therefore examine whether there are any changes in sea level from month to month. In Figure 3 there are shown the monthly heights of sea level in New York harbor and in San Francisco Bay for the year 1919. It is seen at once that the variation in sea level from month to month is less than that from day to day shown in Figures 1 and 2. Between any two consecutive months for the year represented in Figure 3, the greatest difference in New York harbor is a little over half a foot, while in San Francisco Bay it is a quarter of a foot. The difference between the highest and the lowest monthly sea level for the year is about three-quarters of a foot in New York harbor and a little less than half a foot in San Francisco Bay. For accurate determination of mean sea level, therefore, the direct result from a month of observations leaves much to be desired.



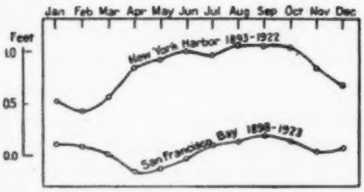


Fig. 3.—Monthly Sea Level, New York Harbor and San Francisco Bay, 1919.
Fig. 4.—Annual Variation in Sea Level, New York Harbor and San Francisco Bay.

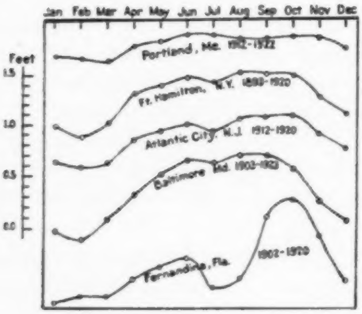
Since the variation in height of sea level from day to day is dependent very largely on the changes in meteorological conditions, it is obvious that such variations are not periodic. In other words, from any one day to the next, sea level may be either higher or lower, depending on the weather. A first glance at Figure 3 may lead one to conclude that the variation in sea level from month to month likewise is not periodic. But a closer examination and comparison with other years brings to light the existence of a large element of periodicity in the variation in height of monthly sea level. While the curves in Figure 3 deviate considerably in outline from regular curves, it is seen that in New York harbor sea level was lowest in the winter months and highest in the late summer and early fall months. In San Francisco Bay sea level stood lowest in the spring months and highest in the late fall months. Sea level therefore exhibits a seasonal change in height, or more precisely an annual variation in height.

It is to be expected that the annual variation in sea level will differ somewhat from one year to another, for weather conditions do not repeat themselves exactly from year to year. However, by averaging the monthly heights of sea level for a number of years, accidental or non-periodic variations will be eliminated and the annual variation will appear in its periodic form. Figure 4 represents the curves of annual variation in height of sea level in New York harbor and in San Francisco Bay derived from a number of years of continuous observations, the figures on the curves giving the length of series on which each is based.

Figure 4 shows that altogether apart from the effects of unusual weather conditions, sea level in New York harbor is lowest in the early part of February and highest in the latter part of August, the difference being somewhat more than half a foot. A secondary maximum and minimum is also indicated in June and July respectively. And it is to be noted that this is not an accidental irregularity in the curve of annual variation of sea level, for this secondary maximum and minimum in New York harbor is definitely indicated by the annual variation curve of sea level for each year. In San Francisco Bay, Figure 4 shows that sea level is lowest in the latter part of April and highest about the middle of September, the difference being a third of a foot. A secondary minimum and maximum is also indicated for San Francisco Bay, occurring respectively in the latter part of November and the latter part of January.

The annual variation of sea level in New York harbor is seen to differ considerably from that in San Francisco Bay. This is not sur-

prising in view of the differences in weather at the two places and the further fact that they are situated on different oceans thousands of miles apart. But it is to be expected that along an open coast or in a large arm of the sea the annual variation in sea level at any point would be representative of a considerable stretch of the coastline in its vicinity. This is borne out by observations and is illustrated by the annual variation curves of Fort Hamilton and Atlantic City in Figure 5. Fort Hamilton is situated in the protected waters of Lower Bay in New York harbor while Atlantic City, nearly a hundred miles to the south, faces the open Atlantic on the coast of New Jersey: nevertheless the two curves of annual variation resemble each other closely. For the Pacific Coast this fact is illustrated by the curves for Anacortes and Seattle in Figure 6. Both places communicate with the open sea through the Strait of Juan de Fuca, Anacortes lying to the north in Washington Sound, and Seattle to the south in Puget Sound, about sixty miles from Anacortes.



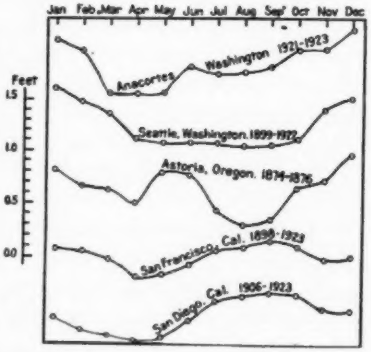


Fig. 5.—Annual Variation in Sea Level, Atlantic Coast.
Fig. 6.—Annual Variation in Sea Level, Pacific Coast.

The annual variation in sea level is thus not of a purely local character. The question at once arises, for how widespread a region is the annual variation at any point characteristic? To answer this question we have at hand the tidal observations at a number of points on both the Atlantic and Pacific coasts of the United States. Figure 5 gives in diagrammatic form the annual variation of sea level at five stations on the Atlantic Coast, while Figure 6 gives it for a like number of stations on the Pacific Coast. The length of the series of observations on which each of these curves is based is indicated on each curve. The same time scales and also the same height scales have been used in the two figures, so that the curves of the one are directly comparable with curves of the

other. It is to be noted, however, that to make the curves strictly comparable they should be based on simultaneous series covering a considerable number of years. This, unfortunately, is not the case, but there can be no question that the period of observations for each of the stations is of sufficient length to bring out the principal features of the annual variation of sea level on the Atlantic and Pacific coasts of the United States.

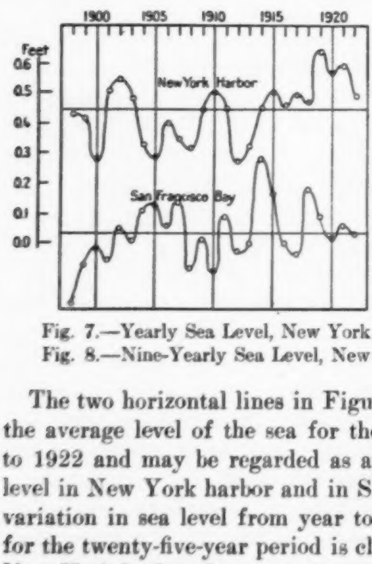
A glance at Figure 5 brings out the fact that along the Atlantic Coast of the United States the range of annual variation of sea level increases from north to south. At Portland this range is barely a quarter of a foot; at Fort Hamilton and Atlantic City it is a little over half a foot; at Baltimore it is more than three-quarters of a foot, while at Fernandina it is exactly one foot. But notwithstanding the relatively great differences in the range of the annual variation of sea level shown in Figure 5, the phase of this variation is seen to differ but little from Maine to Florida. In general it may be said that on the Atlantic Coast of the United States sea level is lowest in the winter months with a minimum in February; from this minimum it rises gradually to a maximum in June, falls slightly to a secondary minimum in July and then rises to the maximum of the year in September or October.

On the Pacific Coast Figure 6 indicates considerable differences in the phases of the annual variations curves and but little difference in the range. The curves for Anacortes and Astoria, each being based on but three years of observations, do not exhibit the regularity of the other curves which are based on longer series. For Astoria another factor is introduced in that it is situated on the only fresh-water harbor on the Pacific Coast and is thus affected by the seasonal variation in run-off from the large territory that drains into the Columbia River. In general, however, it may be said that on the Pacific Coast of the United States north of the Columbia River sea level is low from April to October and high from November to March. South of the Columbia River sea level varies more regularly, with a minimum in April and a maximum in September. The range of the periodic annual variation all along this coast appears to be about half a foot.

In view of its periodic annual variation, sea level determined directly from one month of tidal observations may differ from that of another month by as much as half a foot or more. This difference may be further augmented very considerably by the non-periodic variation from month to month arising from variations in wind and weather. Hence, when sea level is made the basis of studies of a quantitative nature, we are compelled to use observations covering a longer period of time, and

a year suggests itself as a rational period, for during the period of a year the annual variation balances out. We must, therefore, now consider whether there are any variations in sea level from year to year.

VARIATION OF YEARLY SEA LEVEL.—In Figure 7 is given in diagrammatic form the average yearly height of sea level in New York harbor and in San Francisco Bay for the period 1898 to 1922. For each year the height of sea level is derived as the average of the hourly heights of the tide throughout the year. In other words, each of the heights shown in Figure 7 is the average of some eight thousand hourly heights of the level of the sea. The diagram shows at once that both in New York harbor and in San Francisco Bay sea level does vary from year to year, though it is to be noted that this variation is less than that from month to month. Generally the variation in sea level from one year to the next is less than a tenth of a foot, though occasionally it may be as much as a quarter of a foot or even more, as exemplified by the variation between the years 1900 and 1901 in New York harbor, and between 1913 and 1914 in San Francisco Bay.



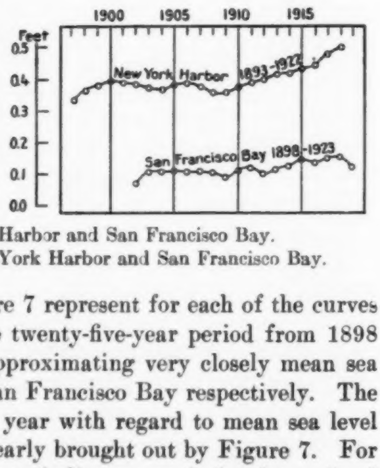


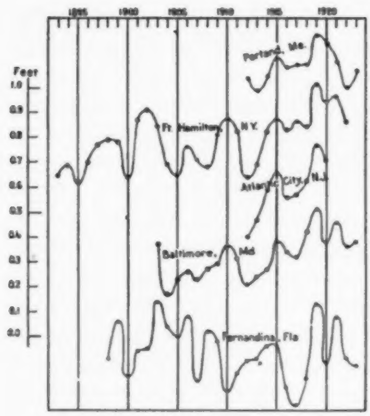
Fig. 7.—Yearly Sea Level, New York Harbor and San Francisco Bay.
Fig. 8.—Nine-Yearly Sea Level, New York Harbor and San Francisco Bay.

The two horizontal lines in Figure 7 represent for each of the curves the average level of the sea for the twenty-five-year period from 1898 to 1922 and may be regarded as approximating very closely mean sea level in New York harbor and in San Francisco Bay respectively. The variation in sea level from year to year with regard to mean sea level for the twenty-five-year period is clearly brought out by Figure 7. For New York harbor the curve appears to indicate a variation in sea level with a period of about four years. Thus the maxima of the curve occur successively in 1898, 1902, 1906, 1910, 1915, and 1919. In San Francisco Bay there appears to be a prominent variation with a period of a little over two years.

These variations of four years in the one case and of two years in the other may be eliminated by taking the sea level averages for successive groups of four years in New York harbor and for two years in San Francisco Bay. But with the elimination of these variations there come to light variations of longer periods. The determination of the periods and amplitudes of these periodic constituents is an exceedingly interesting matter, but one that falls outside the scope of this paper. Here it will be sufficient to call attention to Figure 8 which gives the curves of sea level in New York harbor and in San Francisco Bay by averaging the height of sea level in successive periods of nine years. For New York harbor the curve is based on observations covering the period from 1893 to the end of 1922, while for San Francisco Bay the period of observations is from 1898 to the end of 1923. For each of the stations the variation in sea level from one period of nine years to the next is small, but it is to be observed that in New York harbor during the nineteen-year period from 1904 to the end of 1922 sea level the first nine-year group differs from the last by a little more than one-tenth of a foot.

Manifestly the area over which the variation in sea level is the same depends, in general, on the variation in question. For the variation from day to day this area is of relatively restricted extent. The variation from month to month is much the same over a considerable area, as was illustrated in Figures 5 and 6. It is, therefore, to be expected that the variation from year to year will be much the same over a still greater area. And this the observational material at hand proves to be the case, though from Figure 7 it is obvious that this area does not cover the Atlantic and Pacific coasts of the United States, for the variations from year to year in New York harbor and in San Francisco Bay are seen to be quite independent of each other.

To illustrate the variation in sea level from year to year on the Atlantic and Pacific coasts of the United States there are at hand the results of tidal observations at five stations on the Atlantic Coast and at three stations on the Pacific Coast. These results are shown in diagrammatic form in Figures 9 and 10 respectively. Notwithstanding occasional differences in the variation of sea level from year to year, in general, it appears that if for any one year sea level is high (or low) at one point on the Atlantic Coast of the United States, it is high (or low) all along the coast. And similarly for the Pacific Coast. Thus, for the observations at Portland, Me.,—1912 to 1923—the yearly sea level attained its highest level in 1919, and we find that for this same twelve-year period sea level at each of the other stations shown in



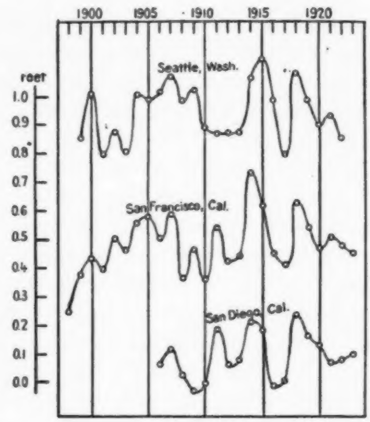


Fig. 9.—Yearly Sea Level, Atlantic Coast.
Fig. 10.—Yearly Sea Level, Pacific Coast.

Figure 9 likewise was at its highest elevation in 1919. In Figure 10 sea level at San Diego is shown to have been in a low-level phase in 1912 and again in 1917, and it is seen that at San Francisco and also at Seattle, more than a thousand miles away, sea level likewise was in a low-level phase during those two years.

The Determination of Mean Sea Level.—In consequence of its variation from day to day, from month to month and from year to year, the accurate determination of mean sea level at any point on the coast is far from being a simple matter. From the foregoing discussion it is evident that along the Atlantic and Pacific coasts of the United States, a determination of mean sea level directly from tidal observations necessitates at least four years of observations, if any pretense at accuracy is to be made, and that nine years is much better.

In studies of coastal subsidence or emergence, sea level determinations from tidal observations constitute perhaps the only data of a quantitative nature. However, if to determine mean sea level at any desired point along the coast required tidal observations at that point covering a period of ten years or more the matter would be very nearly hopeless. Fortunately, the fact that the variation in sea level from year to year and even from month to month is much the same over large areas makes it possible to determine sea level at any desired point from a short period of observations, if at some other point not too far distant a tidal station has been in operation for a number of years. An example will make this clear.

Suppose that in 1912 it was desired to determine accurately the plane of sea level on the coast of New Jersey, say at Atlantic City. This involved the establishment of an automatic tide gauge and also of bench marks which were connected with the zero of the tide gauge by careful spirit levels. The tide gauge having functioned the whole year, the hourly heights of the tide are averaged and it is found that sea level was 10.20 feet below the primary bench mark. The question now to be determined is, what is the relation of *mean sea level* to this primary bench mark? Upon investigation it is found that the United States Coast and Geodetic Survey maintains to the north of Atlantic City a primary tidal station at Fort Hamilton in New York harbor and another primary tidal station to the south of Atlantic City, in Baltimore harbor. At that time the data for Fort Hamilton covered a period of twenty years and at Baltimore, a period of ten years. A comparison of the data for Fort Hamilton discloses the fact that in 1912 sea level was ten-hundredths of a foot below the average sea level for the twenty-year period from 1893 to 1912, while the Baltimore data show that in 1912 sea level was six-hundredths of a foot below the average level for the ten-year period from 1903 to 1912.

From the previous discussion of the variation in sea level from year to year it is reasonable to assume that sea level at Atlantic City will exhibit much the same variations as at Fort Hamilton or at Baltimore. Since the observations at Fort Hamilton extend over a period twice as long as that at Baltimore, the value of mean sea level at Fort Hamilton is given twice the weight of that at Baltimore. By comparing now the values of sea level for the year 1912 at Fort Hamilton and Baltimore with the average sea level of each of these places for the whole series of observations it is determined that at a point on the coast between the two, sea level in 1912 was 0.09 foot below mean sea level based on about fifteen years of observations. Mean sea level at Atlantic City would therefore be determined as 10.11 feet below the primary bench mark.

Had the observations been made in 1919 instead of 1912, Figure 5 shows that since sea level in 1919 was 0.36 foot higher than in 1912, it would have been found that sea level in 1919 was 9.84 feet below the primary bench mark. But by comparing with the results for Fort Hamilton and Baltimore, a correction of 0.23 foot is indicated, making the elevation of the primary bench mark at Atlantic City above a mean sea level based on about twenty years, of 10.07 feet which agrees with the corrected determination for the year 1912 within 0.04 foot. In other words, a difference in sea level of 0.36 foot is reduced to a difference of 0.04 foot.

The example just discussed illustrates well the erroneous conclusion that may result from assuming that sea level based on a year of observation gives a good determination of mean sea level. For on this assumption the coast at Atlantic City, in the period of seven years between 1912 and 1919, subsided 0.36 foot or at the rate of five feet per century. But as our consideration of the matter proves, sea level varies from year to year, so that the direct result of one year of observations may differ considerably from mean sea level. Furthermore, by taking advantage of the fact that the variation in sea level is much the same over a considerable area, the apparent subsidence of 0.36 foot is reduced to 0.04 foot, which is within the limits of error of the observations.

CONCLUSION.—From the foregoing discussion of the variation in sea level it appears necessary, in studies involving sea level data, to specify not only the length of series upon which a particular determination is based but also the dates of the observations, and whether it is a determination directly from the observations or one corrected to a mean value by comparison with the results of a longer series of observations at some point along the coast. Another fact that emerges from this discussion is the importance of long-continued tidal observations at selected points along the various coasts.

A discussion of the causes that bring about the variation in sea level lies outside the scope of this paper. However, in the consideration of the variations to which sea level is subject, it has been implied that changes in wind and weather are the primary causes of these variations. But it is to be noted that in attributing the variations in sea level to changes in wind and weather it is tacitly assumed that the mean level of the sea with respect to a stationary coast remains the same. It is, therefore, to be observed that variations in sea level may also arise from changes in the volume of ocean waters or in the volume of the ocean basins. Recently Daly has directed attention to the probability of a general sinking of sea level, during the Human Period, of about 20 feet.[3]

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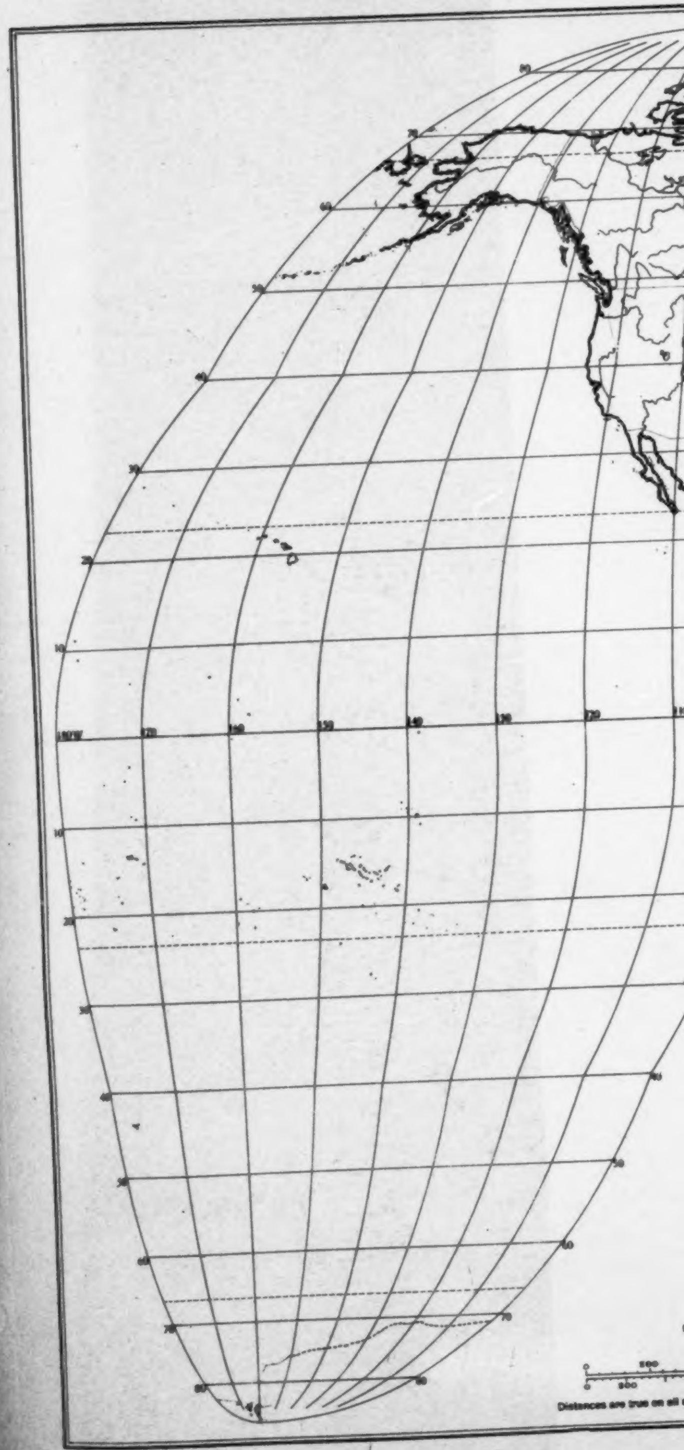
[3]Reginald A. Daly: A General Sinking of Sea-Level in Recent Time. *Proc. Nat Acad. of Sciences*, Vol. 6, 1920, pp. 246-50.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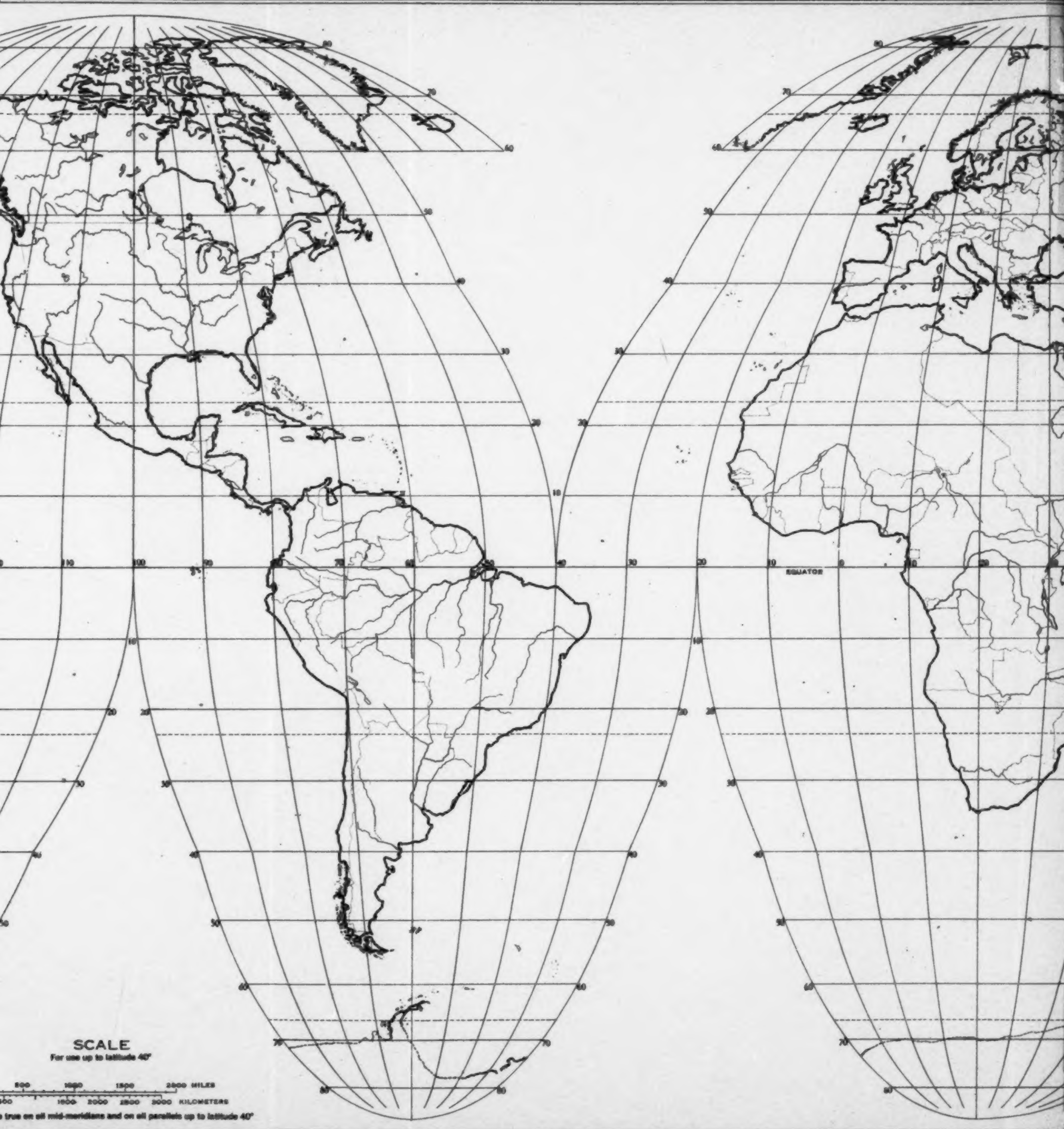

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THE HOMOLOSINE PROJECTION: A NEW DEVICE FOR PORTRAYING THE EARTH'S SURFACE ENTIRE

By J. Paul Goode

For many years it has been patent to many thoughtful geographers, that the use of Mercator's projection as a base map for world wide areal distributions, was illogical, and undesirable.

Now and then some brave soul would, for the sake of having an equal area base map, use Mollweide's elliptical homolographic projection, or even Sanson's sinusoidal, or a phase of Gall's central cylindrical projection. But for the most part it has been easier to drift back to the familiar monstrosity of Mercator, because it *was* familiar. Like Kim's lama, we were "bound to the wheel."

The faults of Mercator's projection are obvious on even the most casual inspection. The most active imagination cannot picture it as the cover of a globe. It does not, as is usually said of it, portray the whole earth's surface. To do that, one would need to carry it to infinity to get to the north pole, and to an opposite infinity to get to the south pole. And for this reason, polar relations can not be shown on it at all. A linear scale can not be used on it, or at least one must have a different scale for each increment of latitude, and no latitude scale can be used on a diagonal. Because of the increase in scale in the poleward direction, shapes and areas are progressively enlarged, becoming enormous in high latitudes.

The great distortion of areas in high latitudes may be graphically shown by comparing the area of Greenland and South America, as shown on the Mercator map, and as shown on the globe. On Mercator's map Greenland seems very much larger than South America, (Fig. 1), though the extent of this exaggeration is usually masked by cutting off the projection at about the mid-point of Greenland. Now, setting South America alongside Greenland as traced from a globe (Fig. 2) it is somewhat shocking to find South America looming up to nine and one-half times the area of Greenland. In like manner, North America is played up to nearly twice the size of Africa, while Spitsbergen puts a number of great nations in Europe to shame.

Now we must never lose sight of the fact that the Mercator map was never intended for geographers' use, or for general use. It was invented by Mercator, on special commission from the merchants of the

Lowlands, as a sailing chart. It was an instant and complete success for that purpose, and it has been in universal use ever since. There is no better device known for the simple and easy laying of an ocean route, and so far as one can see, it is for that purpose the last word.

Fig. 1

Fig. 2

Fig. 1. S. A. vs. Greenland from Mercators Map. On the Mercator Map, Greenland seems much larger than (SA).

Fig. 2. South America and Greenland as they appear on the Globe. As a matter of fact S.A. is nine and one half times as large as Greenland.

But the geographer's purpose is not, as a rule, the "laying of a course." His needs are best met, first by a projection upon which areas bear a true relation to each other, and to the surface of the globe which they represent, that is, an equal area map, and next to truth of area truth of shape is a geographic requisite.

The best alternative for a world map until recently, has been Mollweide's homolographic, equal area projection. This throws the whole earth's surface into an ellipse, the major axis of which is twice the length of the minor axis. But to accomplish this feat, the equator is contracted, and latitudes beyond 40° are expanded. So, although it is strictly an equal area map, *shapes* are badly distorted in regions remote from the equator and mid-meridian. For this reason it has been little used by geographers.

A modification of this projection by Aitoff, puts the earth's surface into the same ellipse, but at the center of the map expands longitude distances, and contracts latitude distances, almost to their true values, compensating for this by contractions and expansions farther out from the center. This device improves shapes all around, but sacrifices the straight parallels of latitude in doing so,—a serious loss.

Observing the advantages offered by the homolographic projection of Mollweide, especially the good shapes provided next to the midmeridian, the present writer in 1916 proposed a method of interruption of the grill, which gave each continent in turn, the benefit of a mid-mer-

idian of its own.[1] To accomplish this, the grill is split down through the oceans, dividing the earth's surface into continental lobes (Fig. 3). This device has a number of advantages. It presents the entire earth's surface, on a strictly equal area projection, retaining the straight line parallels, and giving better shapes to the continents than any

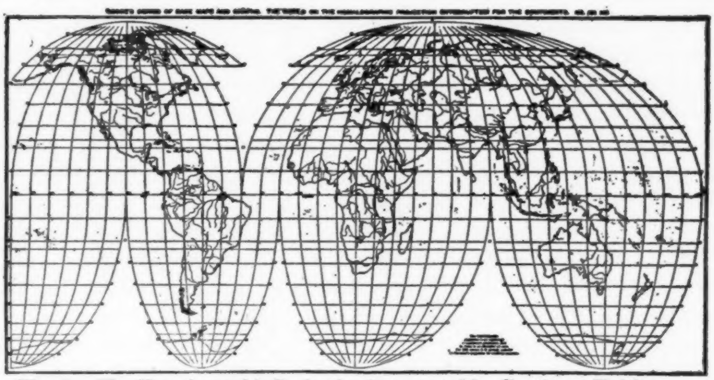

Fig. 3. The Homolographic Projection interrupted for Continent Unities.

other projection hitherto proposed. This method of interruption lent itself also to the presentation of ocean unities, in which case a mid-meridian is chosen for each ocean lobe, on each side of the equator. The resulting map presents the three great oceans, side by side, all in view at one glance, and in better shape for study than even the globe can do. (Fig. 4).

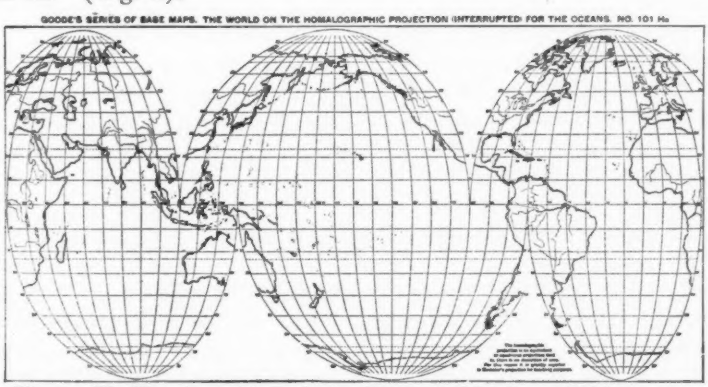

Fig. 4. The Homolographic Projection Interrupted for Ocean Unities.

[1] Goode, J. Paul. Studies in Projections; Adapting the homolographic projection to the portrayal of the earth's surface entire. Bul. Geog. Soc. Phila., Vol. XVII, No. 3. July, 1919, pp. 103-113.

Excellent as the interrupted homolographic projection of 1916 has proven itself to be, there has always been one drawback, hard to tolerate. The fact that the equator is shrunken, and low latitudes expanded, gives us an elongated Africa and South America. This same condition in the projection gives us no uniformity in scale, and a linear scale can not be used on the map.

But there is better provision made for low latitudes than Mollweide's projection offers, in the sinusoidal projection, invented by the famous French cartographer, Sanson, in 1650. In this projection the whole earth's surface is enclosed between sinusoids developed from the mid-meridian as axis. This projection has some exceedingly fine points. The parallels are straight lines trending with the equator, and are true distances apart. On the mid-meridian and on all parallels distances are true. In low latitudes and in the vicinity of the mid-meridian there is little angular distortion, hence shapes are very good. It is strictly an equal area projection. But angles are distorted progressively and rapidly with increase of distance from the mid-meridian, shapes becoming excessively flattened in the margins of quadrants remote from the axis and the equator. For this reason the projection has seldom been used for a world map.

In 1916 the first essay in endeavoring to get away from the Mercator was an interrupted sinusoidal world. But its sharp polar cusps, and the division of Eurasia into two lobes were not acceptable to the geographers at the time, and the interrupted homolographic was adopted instead. When upon a time I made two world maps from the same globe, one in Mollweide's homolographic, and one in Sanson's sinusoidal, and superimposed the two, some very significant relations were seen. The sinusoidal map extended beyond the homolographic at the equator, and also at the poles. And since each projection carries exactly the earth's surface, this extension of the sinusoidal map beyond the ellipse of the homolographic, is compensated for by the limiting sinusoids swinging inside the ellipse of the homolographic in each of the four quadrants. Now, since the limiting sinusoid extends beyond the homolographic ellipse at the equator, a linear scale which can be applied on the sinusoidal equator will show distances too great on the homolographic equator. And a linear scale which will measure true distances on all the parallels of the sinusoidal is found too short for distances on latitude 60 of the homolographic grill. Manifestly there is some point between the equator and latitude 60 where one linear scale will be true on *both* projections.

Having come so far the next step in an important invention is easy. Why not use the sinusoidal grill for the low latitudes, where its service

is at its best, up to the latitude where its scale is identical with that of the homolographic, and beyond that point use the homolographic projection? Now the point of coincidence could be found by superposing the grills. That, however, would be only an approximate solution. I am under obligation to one of my graduate students, Mr. Richard Hartshorne,[2] for having computed the position mathematically. It turns out to be in latitude 40° 44′ 11.8″.

So now I am proposing a new projection for presenting the earth's surface entire, by fusing the sinusoidal and the homolographic projections, using the sinusoidal up to the latitude of equal scale, 40° 44′

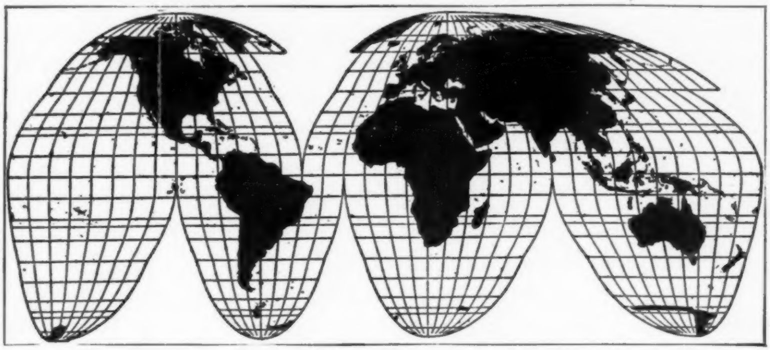

Fig. 5. The Homolosine Projection, Interrupted for the Continent Unities.

11.8″, and finishing out the polar cusps on the lobes with the homolographic projection. An obvious name for this fusion is

The Homolosine Projection, (Fig. 5)

homolo (from homolographic) + sine (from sinusoidal). The projection will be interrupted as in the homolographic of 1916. North America will have for its mid-meridian, longitude 100° W.; South America will be balanced on 60° W.; South Africa on 20° E., all Eurasia on 30° E., for the reason that this gives very good shapes to Europe. Far Eastern Siberia suffers in shape, though not much more than it does in the Bonne's projection in common use for that continent. Australasia will have for its mid-meridian 150° E. The continental lobes will be separated by a sinus at 90° E. for the Indian Ocean,

[2] Now assistant professor of geography in the University of Minnesota.

40° W. for the North Atlantic, 20° W. for the South Atlantic, and 100° W. for the South Pacific. In the North Atlantic lobe the grill is repeated a little to complete Alaska and show the relationship to Asia. It is repeated a little on the east to show continental relationships of Greenland and Iceland. Also there is a slight repetition west of Europe to bring out the relationship of Greenland and Iceland to Europe.

This projection has all the virtues of its predecessor, the interrupted homolographic, and more. For in this projection the shapes of South America and Africa are about as good as any projection can give them singly. Moreover, since the parallels of latitude are shown their true distances apart, and since distances are true on all parallels up to latitude 40°, it follows that a linear scale can be used on this world map up to latitude 40. Beyond 40 the conditions, of course, are the same as they were in the interrupted homolographic, and a scale can not be used. The parallels of latitude are preserved as straight lines parallel with the equator.

As in the interrupted homolographic of 1916, this projection lends itself to presenting the oceans as units, and provides an excellent base for the plotting of a wide variety of marine data.

Upon this new projection all areal distribution of whatever data, can be better shown than upon any projection in the equatorial aspect hitherto in use. The supreme advantage of this projection is patent when a density distribution per unit area is to be shown. It is an absurdity to enter upon a Mercator the area of the British Empire or any other empire, or areas of dense or scant rainfall, or forest or grazing areas, or wheat or any crop per square mile, or population density, or any other density datum. This absurdity may now be avoided by entering such data upon the homolosine projection, interrupted for land unities, or for ocean unities as the case may require. Hereafter the use of Mercator's projection for such purposes, in the interest of rational education, should be discontinued. From now on the use of a Mercator for any density distribution, or areal comparison should be considered a pedagogical crime.

The new projection offers practically all the advantages of the Mercator save one, the laying of a mariner's course. It is far superior to the Mercator for all other geographic purposes, and it makes it unnecessary from now on to impose upon the student the enormous distortions of distance and area, which are the principal faults of the

older projection. Nor is there any particular fault in this new map which may stand in the way of the best teaching. The ease of study of comparative latitudes is maintained. The whole earth's surface is shown. The continents and oceans are given better form than is possible with any other world map presented in the equatorial aspect. In short, more truth and less error are presented in this projection than in any alternative projection which carries the earth's surface entire.

SOME GEOGRAPHIC ASPECTS OF WESTERN ECUADOR*

By HUGH H. BENNETT

Western Ecuador will be treated as comprising two of the three major physiographic regions of the country: The Pacific Lowlands and the Andean Highlands. The former covers about 20 per cent of the area of the entire country, and the latter about 35 per cent, the remainder of the territory comprising the Trans-Andean or eastern lowlands.

Pacific Lowlands

This division embraces the lowlands lying between the western base of the Andes and the Pacific Ocean, representing an area of about 30,000 square miles, with a maximum width of about 140 miles and a maximum length from the boundary of Peru to the boundary of Colombia of about 365 miles, according to the Tufiño map.[1] Its dominant topographis aspect is that of a plain sloping gradually toward the sea, locally diversified by isolated mountain ranges and hills having no association with the Andes and by flat alluvial bottoms and benches. In places mountains rise abruptly above the plain to an elevation of 3,000 feet. The principal elevated areas are those of the Colonches Range, the Guayaquil Hills (or Cordillera de Chongón), the Paján Hills, and the Cojimies Mountains. In addition to these higher elevations, there is much hilly country, such as that lying to the south and north of the Manta-Montecristi Plain.

The regions of most favorable topography, from the standpoint of agricultural use, are: (1) A belt of seaward sloping country contiguous to the western base of the Andes, which has been built up of material washed out from the lofty range on the east; (2) the flat alluvial lands, such as those bordering the Guayas River and its tributaries; and (3) the flattish coastal areas of the Santa Elena Peninsula and the Manta-Montecristi Plain.

The principal subdivisions of the Pacific Lowlands are roughly indicated on a reconnoissance topographic map developed from the recently published Tufiño map. These subdivisions will not be described in detail, except in the case of the colluvial plain skirting the Andes and

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* Read at the Annual meeting of the Association at Washington, D. C., Dec. 31, 1924.

[1] The greater part of Ecuador's boundary is in dispute, both on the Peruvian and Colombian sides. The map presented is used merely as a map of physical conditions without any reference to the accuracy of national boundaries.

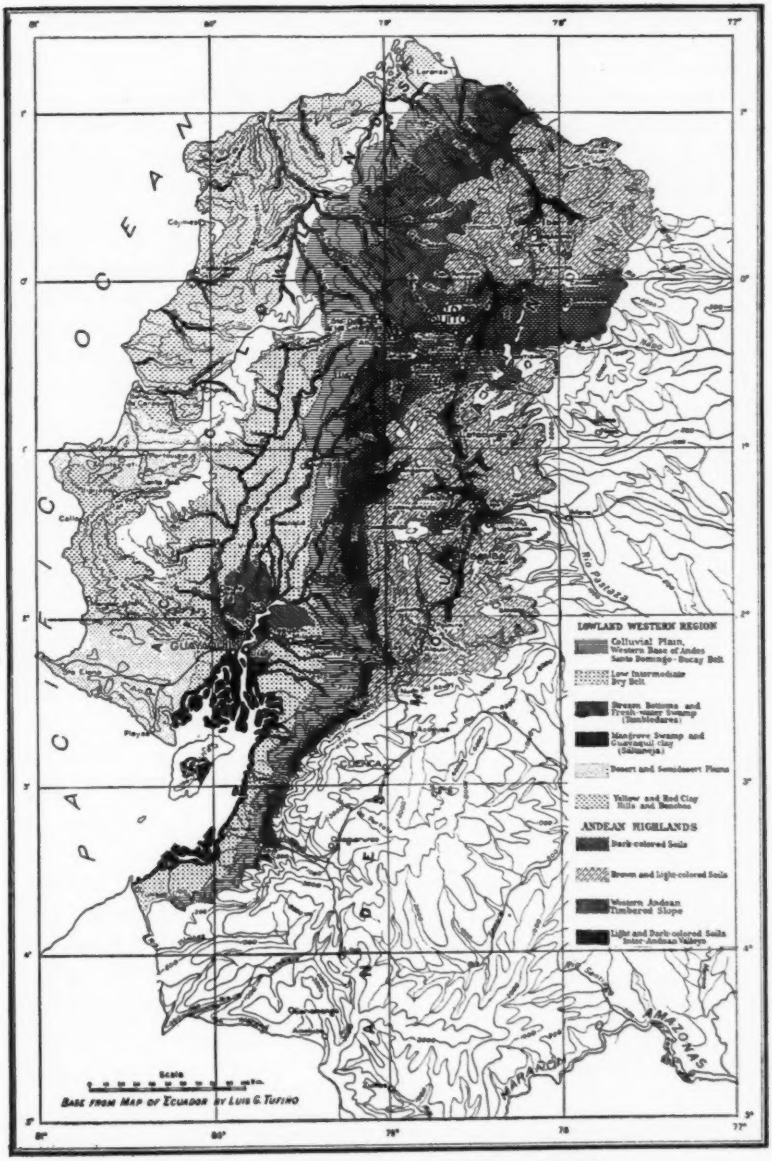

Fig. 1. Soil Reconnaissance of Western Ecuador.

the alluvial lowlands of the Guayas-Daule-Palenque-Zapotal[2] river system.

Santo Domingo-Bucay Belt.—The colluvial strip along the base of the Andes (see legend of Fig. 2) will be referred to as the Santo Domingo-Bucay belt. This extends along the entire length of the Andes in Ecuador, with its broadest development in the northern part, in the vicinity of Santo Domingo de los Colorados. A reconnoissance estimate puts its area at about four million acres. Further exploration might show a considerably broader development in the northern extension than is indicated on the generalized map. At least three-fourths of the area is topographically suited to agriculture; everywhere the soil was found to be of excellent quality, deep, mellow, rich in organic matter to unusual depths, and highly resistant to erosion. The unfavorable part consists of steeply sloping land along the streams that cut across the plain.

The average inner elevation from north to south is close to 1,700 feet. East of Bucay the highest elevation is about 1,200 feet, while the corresponding position east of Santo Domingo de los Colorados is 2,200 feet. From this higher inner line the plain slopes westward at a maximum rate of about 70 feet per mile in the northern or broadest part; toward the south the slope is much more gradual.

Climate.—The climate prevailing over this plain is characterized by two markedly contrasting seasons, as relating to rainfall: A definite wet season, from January to May, inclusive; and a long dry season, from June to November, inclusive, with rains usually beginning in December. Precipitation is generally lightest in October and November and heaviest in January, February, March and April, May usually having considerable less rainfall than April. The annual rainfall ranges from around 90 to 125 inches. The region is locally referred to as the "rain belt," as for example, in the section about Bucay. Here the belt is bordered on both the higher Andean side and on the lower Pacific side by distinctly dry zones, in which the impress of the rainless season is sharply evidenced by the abundance of leafless trees and dried grass during November and December. Toward the north such sharp lateral zonal differences do not exist, at least not in the section from the Toachi River to the lower Palenque.

[2] The Zapotal here referred to rises on the Pacific slope of the Andes near Angamarca and enters the Guayas (or Bodegas) northeast of Guayaquil. A smaller stream also known as the Zapotal flows across the dry plain southeast of Guayaquil, entering the Gulf of Guayaquil.

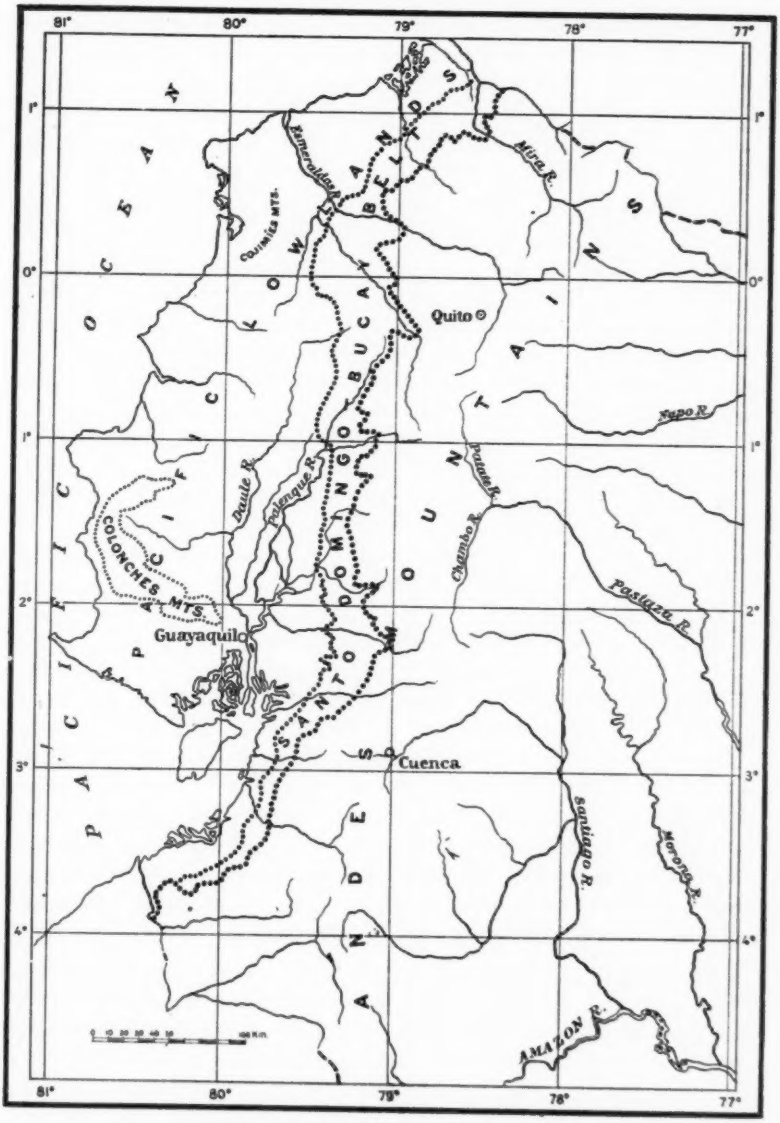

Fig. 2. Sketch Map of Western Ecuador.

At San Rafael in the province of Guayas the total precipitation in 1921 was 125 inches. Of this 113 inches fell during the period of January to May, inclusive, or more than nine times as much as fell during the other seven months of the year. This condition appears to approximate the prevailing humidity of the Santo Domingo-Bucay belt, although the precipitation locally drops to 100 inches or less, according to the evidence obtained.

Characteristically, there is a dry season of at least six months duration, and in some places almost no rain falls during this period. Under ordinary conditions it would be expected that such prolonged drought would result in severe desiccation of the soil and vegetation; but this does not happen—in fact, opposite conditions were found to prevail. Our party reached Santo Domingo de los Colorados in December at about the close of what was described as having been an exceptionally long dry season (" the longest since 1914 "), and subsequently traveled elsewhere through the belt on trips toward the Pacific, down the Palenque River, and again inland near Bucay, without seeing any very marked effects of drought, except on the shallow gravelly and sandy alluvial soils, the reddish clay lands of the Vinces locality, and in the contiguous dry belts. The soils of the Santo Domingo-Bucay colluvial plain were moist from the surface down, the forests were green, as were, also, all of the cacao and banana groves and the pastures. The summer growth of weeds, bushes and vines was exceedingly rank in all clearings. No marked check in the growth of plants was observed; at no place was the grass dry enough to start a fire, not even in pastures. The Castilla rubber tree and one or two others had dropped most of their leaves, but all others of the great variety of trees were covered with dense, deep-green foliage, shedding their leaves a few at a time in the way of a normal humid tropic jungle. Bananas were heavily fruited near Bucay and in other plantings seen through the belt, although they were said to bear not so heavily as during the wet season. However that may be, the fruit seen was all of good quality, of large, well-developed " fingers " and bunches.

The rankness and greenness of the vegetation throughout this zone at the close of a season of seven months dry weather represented an extreme contrast to conditions observed on the stiffer clay lands in central Pacific-Panama upon returning there in the dry season of 1924. By the middle of March grass was completely parched on the Panama savanas, as was also, most of that on the other upland soils, and bush fires were frequently observed. In much of the forests 75 per cent of the trees were leafless, as much as 95 per cent on shallow limestone soil

in the Chagres Valley. At this time the dry season was but two months old, yet its effect was that of a highly desiccated condition of both soil and vegetation. Similar parched conditions were observed on the reddish clay of the Vinces section near the western edge of the moist belt in Ecuador.

The moisture retentiveness of the deep, friable soils of the Santo Domingo-Bucay belt, coupled, perhaps, with some underground seepage, almost completely obliterates the drying effect of the long dry season in that region, and gives this part of the Pacific Lowlands large possibilities for agricultural development. In the ecological sense this unusual relation of soil to moisture amounts to a wide departure from the story told by rainfall tables and charts.

Present Use.—The northern part of the belt is largely covered with heavy tropical forest; but considerable areas in the more accessible southern part are in use for the production of cacao, bananas and plantains. Only scattered farms, mostly of small size, were seen in the northern part, which at present has very inadequate means of transportation. These farms were producing good yields of bananas, cacao, corn, cotton, achiote, citrus and other fruits—yields which attest the excellent productivity of the soil. Better physical condition of soil for easy cultivation, resistance to erosion, and retention of moisture, could not be desired than those characterizing the soils here. Gullies are nowhere to be seen, not even on the steeper slopes, some of which are used for bananas. Cultivation, however, is not one of the habits of the people of this region. Weeds are slashed occasionally, but the plow is not one of the implements of the farmer. In but one instance was plowed ground seen within the belt, and that was on a banana farm of an American near Bucay.

Vegetation.—The forests include much good timber, but little use is made of it, except in the construction of leaf-covered houses, made largely of small poles, with bamboo flooring and siding. Bamboo (caña de Guayaquil) is the most valuable forest product. It is rafted down the streams to the villages and to Guayaquil where it is extensively used in the construction of houses, for scaffolding, fences and other purposes. This plant grows to a height of more than one hundred feet, with frequently a basal diameter of 5 or 6 inches. It is locally plentiful on the humid alluvial soils of the Pacific Lowlands, and is found abundantly on the uplands in parts of the colluvial region.

The forest trees prevailingly are tall and erect; they frequently range up to four feet in diameter, and are varied in kind, pure stands of any genus or species almost never being found, with the exception of bam-

boo. The tough *chonta* palm is one of the most conspicuous trees in the northern part of the belt, and bamboo in the southern part. Many of the well-known tropical trees were seen in the region, such as balsa, guayacan, espavé, fig, aguacate, guarumo (*Cecropia*), cedro, laurel, ceiba, and caucho (*Castilla*). The tagua or vegetable ivory palm is widespread, and from it some nuts are harvested. It is not here worked nearly so extensively as in other parts of the lowlands, as in the Manta and Esmeraldes localities, near the coast. A million or more of Castilla trees have been planted, but most of the groves have been abandoned and are growing up to jungle. At the present time little rubber is being taken from either wild or planted trees, owing to low prices. Formerly it was an important article of commerce. Probably rubber plantations would have been more profitable, had the Para tree (*Hevea brasiliensis*—or Amazon Valley rubber tree) been planted, since it was the tree of all the kinds tried that brought such success to the East Indian plantations.

Toquilla (*Carludovica palmata*), the plant used in the weaving of Panama hats, is abundant, but is not used in this section to any important extent. (The Panama hat industry centers about Montecristi near the Pacific Coast). Some cheap hats of durable quality are woven of the bark of a common palm known as the *mocara*.

The undergrowth on the uplands of the lower Andean slopes generally is not so dense but that one can travel rapidly through the forests by slashing a few vines and small plants. Much greater difficulty is experienced in getting through the dense second growth, and on the alluvial areas the virgin growth often consists of dense jungle through which travel is slow and tedious. Here vines climb over the bamboo, tree ferns, wild plantain, *caña bravo* and other plants in such weighty mass as to bear their hosts almost to the ground, making a nearly solid mass of intertwined vegetation. Caña bravo, a wild cane, grows tall and dense in moist places. It is one of the most widely used plants of the tropics, entering into the construction of both rural and village dwellings.

Available Land.—It is estimated that fully three million acres of fertile land of favorable topography awaits agricultural development in the Santo Domingo-Bucay belt alone. As stated, there may be considerably more land of the same excellent quality in the northern part of the region. In addition, there is much unused, well-drained valuable stream bottom, not only here, but generally throughout the humid lowlands.

This upland area, together with associated and outlying bodies of unused alluvium, is a valuable asset to the nation. Its development awaits the construction of highways and railroads.

Agricultural Products.—The alluvial bottoms and benches are extensively used for cacao. Along the Palenque, Doule, Zapotal and other rivers there are many large and small cacao plantations. This is the upper district from which the *cacao arriba* is obtained. The product from the plantations nearer the coast is known to the trade as *cacao abajo.*

Cacao is the principal export product of Ecuador. In recent years two diseases, *monilla* and *witch broom,* have made destructive inroads upon the output of this most important crop, the damage amounting to a national calamity. Some plantations reported as much as 90 per cent reduction of yield from *monilla.* No effective remedy for this disease has been discovered, but it is claimed that for the last few years the damage has been much lighter. Some growers believe that this disease is waning in its virulency.

Low Intermediate Dry Belt.—West of the "rain belt," along the western base of the Andes Mountains precipitation is much lighter, and the soil conditions much more varied. Sugar cane is an important crop on the brown and dark-colored, well-drained sandy and loamy soils of the alluvial benches between Naranjito and Milagro along the Guayaquil-Quito Railroad. Rice is also grown in this locality. For these crops plowing is regularly done in preparing the seed bed. The included stream-bottom soil is of good quality, about like that of the Santo Domingo-Bucay area. It is probable that there is considerable good sugar cane land between and near the large rivers that flow down from the north.

Guayas River Lowlands.—The lower part of the Doule-Palenque-Zapotal delta and the flats bordering the Guayas River, to 15 or 20 miles below Guayaquil (indicated on the map as *Mangrove Swamp and Guayaquil Clay*), are occupied largely by gray and black stiff clay of the "gumbo" type. When wet this is of a sticky nature, but with the desiccating effect of the dry season it hardens and cracks, and the luxuriant grass cover of the wet season parches. These *saltaneja* or savana lands support a few small acacias and *madera negro,* in places; elsewhere they are treeless. They are entirely used for fattening stock, chiefly cattle, and, owing to the intractable character of the soil during the long dry season, this obviously is the best use to which the land can be put, although some of it might produce fair crops of sugar cane. In addition to the native grasses, Para grass is extensively used here for

grazing. Apparently hay is never harvested, except as grass cut green for immediate use, chiefly in the larger towns and Guayaquil. Rice could be grown, if fresh irrigation water could be economically applied.

On these clay flats water accumulates during the wet season, especially where there are high banks, natural levees along the river fronts which impede the flow-off. Some of the streets of Guayaquil are inundated at this time of the year.

Dwellings.—Cattlemen live in houses built upon the common dome-shaped mounds that occur through the flats. Their houses stand upon posts from 8 to 12 feet above the ground, giving the impression of having been thus constructed to lift the dwellers above the water and mud of the rainy season. This type of structure, however, is typical for the entire area of the Pacific Lowlands, and is to be seen half way up the trails ascending the western slope of the Andes. It is as characteristic of the desert areas along the Pacific as in the *saltanejas* or in the " rain belt " at the foot of the Andes. It is possible the original idea of building houses thus upon stilts was protection from flood or standing water. The platform or dwelling floor is usually reached by climbing a pole with notches cut into it for steps. Some practice is necessary to make the ascent gracefully. The better homes sometimes have stairways.

Chicken and pig pens are frequently seen beneath the house; in nearly all cases some kind of animal is to be seen in the open space beneath, and often small quantities of cacao and other crops are stored underneath the dwelling.

The savanas of western Ecuador closely resemble the coastal prairie country extending from Lake Charles, Louisiana, westward along the Texas coast, although there are no isolated areas of pine.

Tembledares.—Associated with the " gumbo " flats are some extensive bodies of swamp land—low areas which are either covered with water or are wet at all times. These are the *tembledares,* that is, fresh-water swamp or marsh land. Cattail, gamilote grass, and *saggitaria* compose the principal natural cover, with here and there a mangrove tree. Cattle graze through the swamps in the dry season when the water is low. On the reconnoissance map these areas are included with the *Stream Bottoms and Fresh-water Swamp* subdivision.

Coastal Swamp.—Toward the coast fresh-water swamp gives way to salt-water swamp, the common mangrove swamp of the tropics, known as *mangles.* These have no value except that some mangrove is taken out for the extraction of tannin. They are shown on the accompanying map with *Guayaquil Clay.*

Along the Canal de Jambeli at Puerto Bolivar some interesting features were observed in a low strip fronting on the water. Amidst tide-swept, permanently water-soaked mangrove swamp and saturated sand flats are to be seen exceedingly dry isolated sandy hummocks supporting desert vegetation of cactus and acacia, along with some heavily fruited, small-bolled wild cotton.

Intermediate Swamp.—An intermediate type of land between true savana and fresh-water swamp is characterized by being swampy in the rainy season and dry during the last half of the dry season. This supports an aquatic type of vegetation, most of which becomes dried out and leafless by the first of December. East of Guayaquil there is a considerable area of this land which by drainage could be made available for the culture of rice and possibly sugar cane. On the general map it is included with *Stream Bottoms and Fresh-water Swamp.*

The range of hills extending in a northerly direction through Guayaquil, which we will call the *Guayaquil Hills,* is covered with thin soil, often rocky. This has little value aside from grazing. Some patch farming of the milpa type is done here and there on the gentler slopes, but this is of little importance. Practically all vegetation is parched by the close of the dry season, the characteristic small trees being largely deciduous.

Pacific Coast Region.—The western portion of the Pacific Lowlands in Ecuador consists of, (1) flat plains, (2) ranges and groups of hills and mountains, and (3) isolated hills, without any directional regularity of occurrence (see map). Climatically, the regional range is from, (1) desert, through (2) intermediate-humid or subhumid, with about 30 to 50 inches of rain, to (3) wet, with more than 50 inches of rain.

Most of the coast region between Bahia de Caraquez and the Guayas River is desert, but there are several isolated wet belts, due to local topographic conditions—the influence of such elevations as the Colonches Mountains and Paján Hills in causing precipitation from moisture-laden winds off the Pacific. From Bahia northward the coast is wet, with probably more than 60 inches of rain at Esmeraldas. Inland from this part of the coast there is said to be considerable rainfall right on up to the Andes.

The remainder of the coast country, with the exception of the limited local wet areas, is too dry for the production of the ordinary crops. These arid and semi-arid regions support a growth of giant cactus, dry-land shrubs and small trees, with a scanty cover of grass. They are used for the raising of goats and cattle. A representative dry area, the

Santa Elena Peninsula, has been described recently in a paper by Bengtson, published in the Annals of this Association.[3]

From the shores of the Pacific south of Manta eastward to the western base of the Andes the prevailing order of climate, by zones, is: (1) desert zone, (2) dry zone, (3)sub-humid one, and finally (4) the wet zone of the Santo Domingo-Bucay region. Not all of the coastal region, however, is desert; but desert conditions occur within this region only.

The soils of the coastal humid regions which are approximately coextensive with the *Yellow and Red Clay Hills and Benches* subdivision shown on the map, are not particularly favorable. There is rather too much clay land or the terrain is too generally hilly. Most of the soil is a brown clay, with a stiff, yellow clay subsoil, derived from shale, clay beds, and to some extent from limestone. That from limestone is of better quality, and produces corn and other crops where the dry season is not too severe and the surface too uneven.

The prevailing topography of the wet areas, as seen at Callo, Bahia de Caraquez and at Esmeraldas is entirely too hilly, as a rule, for cultivation. At Callo the hills begin at the shore and rise rapidly inland to mountains upwards of 2,500 feet altitude. Here the country is very rough, without topographically favorable land, except for occasional small bodies as the flat just north of the village. This is only about two or three miles long, and a mile wide, approximately, at the broadest place. It stands about 150 feet above the sea, with a clifflike escarpment along the ocean front, such as characterizes most of the Ecuadorean shore line.

Both to the north and south of Callo the characteristic coastline is a sharp escarpment, bare or nearly bare of vegetation, composed of yellow sedimentary clay or clay derived from sedimentary rocks, and standing something like 50 to 300 or 400 feet high. Back from the coast the surface is flattish, with a gradual rise toward the east. There are terracelike step-ups in places toward the east. Unfortunately, the rainfall is so light as to preclude the growing of the general farm crops, much or most of the country supporting desert vegetation.

Manta is situated on the edge of a desert plain which extends to a considerable distance inland toward the base of the Paján Hills and Balzar Mountains. At Manta and as far as the eye reaches from this place, the country is desert, the vegetation consisting of giant cactus and other dry-climate plants of stunted growth. The soil is a light-

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[3] Some essential features of the Geography of the Santa Elena Peninsula, Ecuador, Bengtson, Nels A. *Annals of the Assoc. of Am. Geographers*, V. XIV, No. 3, pp. 150-158, 1924.

colored fine sandy loam, overlying loose sand with a high content of lime. At depths of about two to four feet a whitish limestone conglomerate (small gravel and shells cemented) was found in the borings made.

The rainfall increases toward the hills on the east, but there probably is not sufficient precipitation for successful crop production until within a short distance of the foot of the hills. Montecristi, famous as the place where the best Panama hats of the world are made, is built on the Manta Plain. Manta exports tagua nuts and Panama hats. A railroad extends from the port to Portoviejo via Montecristi.

At the village of Bahia de Caraquez, where there is considerable rain, the country is very hilly and the soil predominantly is a yellow clay which is plastic and sticky when wet. Back from the coast better soil and more favorable topographic conditions are to be found locally. Tagua nuts, cacao, coconuts and small quantities of copra, hides, ceiba wool, balsa wood, and rubber are exported.

From Bahia de Caraquez to Esmeraldas the country is quite hilly, as it is, generally, northward from the latter place into Colombia. It is very hilly about Esmeraldas, the slopes rising to 800 feet above sea level immediately back of the village, and to 1,500 or 2,000 feet two or three miles up the Esmeraldas River. The soil is yellow clay like that at Bahia and Callo, and is derived from the sedimentary beds of claystone and shale that form the regional hills. Limestone beds occur in places.

The valley of the Esmeraldas River to beyond the mouth of the small tributary stream, Rio Mutile, varies from about one-half to three-fourths of a mile in width. Its floor is occupied by shallow loam soil overlying sand. On the higher benches the soil is of the same order, but it is deeper and better. Hills rise abruptly from the margin of the alluvial plain, and while some patches on the slopes are used for crops, most of the upland here is too rough for cultivation. Good soil was seen in the valley of the Mutile River, but the extent of this probably does not exceed three or four thousand acres of good soil as the valley floor is only about one-half mile wide near its junction with the Esmeraldas River. Other tributaries of the Esmeraldas may have equally favorable soil conditions, and, too, better lands may occur immediately along this large river farther upstream.

Shipping Conditions.—There are no docks for ocean craft in Ecuador. Even at Guayaquil steamers anchor in the river and discharge and take on cargo by lightering. In the river there is no swell to impede loading and unloading, but at the ocean ports, such as Esmeraldas, Manta and Caraquez, small craft taking on and discharging cargo alongside

steamers anchored off shore often are difficult to handle in the heavy ground-swell, although the business is always accomplished eventually. Cattle are made to swim out to the steamer in tow of dug-out canoes, where they are swung aloft and into the ship's hold by ropes fastened to their horns. The hornless beasts present special problems of handling. There is no lack of steamer service notwithstanding the unsatisfactory port conditions or rather the absence of docks in Ecuador.

The lower rivers are navigated by launches regularly. These ascend much higher on the swollen waters of the rainy season. Considerable farm produce and forest products are brought downstream by the large canoes of the natives and on rafts.

Summary.—Summarizing the outstanding features of human activity in the Pacific Lowlands of Ecuador, it is to be observed that the region is essentially agricultural. A little petroleum is produced; Panama hats and a few other articles are manufactured; forest products, chiefly vegetable ivory, Castilla rubber, chemical wood from the mangrove swamps, and bamboo, are of some importance; fishing in the coastal waters is carried on chiefly for local consumption; and of course shipping is very important at Guayaquil. But the production of cacao and the raising of cattle constitute the backbone of productive activities in this region, the former contributing approximately fifty per cent of the nation's exports.[4]

The things that control production, aside from the labor of man, are climate, topography, and soil. In the driest localities, where sometimes no rain falls during the year, practically nothing is produced and the inhabitants depend upon sea fish for their food. On the other hand, all the land is not productive, even where rains are abundant. Some is too rough, some too swampy and some too clayey for profitable crop production, although having usually some value for grazing. It is on the good land, and only on this, that marked success has been attained with agriculture. Looking to the future, it is believed that the banana will take a place of importance equal or almost equal to that of cacao. Already shipments of bananas are going to Pacific ports south of Ecuador, and to the Andean Highlands within the country. There is an abundance of land which is admirably adapted to this fruit. Transportation should develop the industry. There are promising possibilities also for plantation production of Para (*Hevea*) rubber, and of increased production of cotton, sugar cane and henequen.

[4] Supplement to Commerce Reports; *Trade and Economic Review for* 1923, No. 13, U. S. Department of Commerce.

There is yet to be brought into cultivation more of the better quality of land than thus far has been used for agricultural purposes of any kind. Not less than five million acres of very fertile soil remain to be cleared in the Pacific Lowlands. Most of the unused area is without inhabitants, save for an occasional family or two cultivating isolated patches of ground. Along the rivers much of the better land is in use, and villages and rural homes are abundant. It is back from these streams and along the lesser streams that so much unused land of good quality is to be found.

Development of transportation by railroad will not present any particularly difficult problems in this region. By easy grades lines may be extended from the northern ports to the foot of the Andes over ground with very little swamp. Some difficulties will be encountered in getting through the isolated ranges and hilly sections, but much of the country will admit of easy highway and railway construction. Already surveys have been made from the northern part of the Ecuadorean highlands to San Lorenzo, and some construction accomplished along the interior part of the line.

At present considerable cacao, some cotton and other products are carried over trails that follow several of the stream valleys up the Pacific slope of the Andes to Quito and other Andean towns on the Guayaquil-Quito Railroad. Similar products go down to Guayaquil by raft and canoe, and large quantities of cacao from the big plantations along the middle and lower rivers enter that city by gas and steam boats.

Any important increase in the area of tended ground will require much more labor than is to be found in the rural districts. The present rural population is composed of pure Indians, such as the Colorados; Indians of the Andean Highlands type; mixed Indians and Spanish; blacks; and mixed black, Indian and Spanish. Those of pure Spanish stock are in the minority. Where encountered outside of the cities they are usually the owners or managers of the larger plantations.

Andean Highlands

The Andes Mountains of Ecuador are made up of an eastern and a western range. These enclose a longitudinal valley or trough, whose floor lies many thousands of feet below the snow-covered summits of the lofty peaks in the parallel east and west ranges. In detail there are a large number of lofty peaks, Chimborazo lifting its summit to more than 20,000 feet above the sea. There are steep-walled valleys, canyons, cliffs, and a succession of irregularly shaped lateral ridges as well as ridges which cross the great trough to cut it into a series of sub

Fig. 3. Showing complete utilization of lower slopes and valley lands of the inter-Andean Highlands for crops, eucalyptus trees and pastures. Looking in a westerly direction, up the slope of the water range of the Andes from a point about 10 miles south of Quito.

Fig. 4. Grassland on Pichincha Mountain. These high, cool grass-covered areas, known as paramos, extend from about 11,500 or 12,000 feet up to rock outcrop or thin soil practically without vegetation. Horses and mules graze over these bleak areas, but no cultivation is carried on.

ordinate valleys or basins. A well-developed but not intricate stream system drains the region, the waterways flowing north or south through the basins, finally to pass in an easterly or westerly direction through the enclosing ranges to enter the Atlantic or Pacific Ocean. In the southern part of the country, south of Cuenca, there is less regularity in the orographic features, although still preserving a tendency toward parallel ranges with enclosed valleys. Still farther south in Bolivia and Peru the Andes attains its broadest development and highest altitudes. In Ecuador, however, the range is of tremendous proportions, the altitudes great and the scenery majestic.

The inter-Andean basins are not continuously flat-floored, nor of even elevation. Their floors range from about 8,000 to 10,500 feet above sea level. The flattish areas merge into gently rolling and hilly land along the margins, and these uneven lands in turn, pass into steeply-sloping mountain sides. The lower areas are in most instances flat to undulating, and admirably suited to tillage. The less rolling of the marginal lands, also, are easy to till. Tillage, however, does not stop with these areas, but extends to mountain sides so steep that it is impossible to plow them and none too easy to operate with hand implements. On these steeper declivities the fields are divided into small plots bordered with terraces and walls necessary for the prevention of erosion. In the matter of soil conservation the industrious descendants of the Incas and pre-Incas, now cultivating the steep inter-Andean slopes, could give the American farmer valuable instruction, so skillful are they in caring for their sloping fields.

The lower lands of the basins while predominantly flat often occur as benches separated by steep escarpments, which in some instances are several hundred feet in height. The village of Calderon, for example, sits upon a broad flat to slightly undulating bench of the Quito Basin overlooking another bench nearly a thousand feet below, through which flows the Guallabamba River in a deep gorge.

After making the difficult ascent of the western slope of the Andes east of Bucay, the Guayaquil-Quito Railroad passes northward through the great inter-Andean depression for a distance of 185 miles, from Palmira to Quito, ascending and descending the transverse ridges (*nudos*) and crossing wide expanses of flat and gently rolling country. One is carried from well-tilled fields of corn, meadows of alfalfa and groves of eucalyptus up above the line of crop production into the cool grass lands of the páramos. Along the entire route the scenery is intensely interesting, often majestic, and the inhabitants in their colorful ponchos are always picturesque. Chimborazo, Cotopaxi, Antisana,

Cayambe and other lofty, snow-covered peaks stand out in the sunlight majestic monuments of dazzling white. The lesser peaks standing closer by, with their cultivated slopes, often have a pyramidal appearance in the purplish haze of the valleys. South of Quito the train swings past and high above the fertile and well-tilled Chillo Valley, whose wall-inclosed green fields, meadows, eucalyptus groves, and red tile-roofed buildings afford a most pleasing view. There are arid and semi-arid regions of much more barren aspect, however, such as the slopes west of Latacunga, where the whitish ash-covered mountain sides support but scant vegetation.

Climate.—The climate of the Andean Highlands varies with the altitude from humid-tropic along the base to very cold on the summits of the high peaks. Precipitation ranges from amounts so low as to give rise to desert conditions to more than 100 inches in places near the base. Generally, precipitation is low in the great trough, probably not much over fifty inches anywhere, and often less than twenty inches. At Quito the rainfall is about forty-five inches; twenty miles to the north it is less than eighteen inches. There are two seasons, a rainy season and a relatively dry season. June to September, inclusive, is the time of the dry season at Quito, with relatively dry weather sometimes extending into November. The average number of days with rain at Quito is 171. Showers may fall at any time of the year. These are often accompanied with thunder and not infrequently by hail. Similar conditions exist at Ambato, even though the rainfall is only 18.5 inches. The mean annual temperature in Quito at an elevation of 9,500 feet is 54.70° F., the highest is 79° F., and the lowest 35° F. At Ambato, elevation 8,500, the mean temperature is 57.70° F., the maximum 81°, and the minimum 32°. Diurnal variation is about 10° F. Frosts sometimes kill potatoes and corn at Quito and in other parts of the inter-Andean depression. If these crops are killed in December they are plowed up and the fields sown to grain. Occasionally there is a damaging frost in March. June frosts occur also, but at a time when most of the crops are too well along to be seriously injured.

Farming is restricted to the slopes and valleys lying below the bush zone immediately skirting the lower limits of the high grass lands, potatoes being the main crop at the higher elevation. Barley is grown up to about 11,500 feet and some wheat up to about 10,500. The upper limit of corn production, according to the fields seen, is about 10,000 feet.

Population.—The greater part of the Andean population of Ecuador is found at elevations ranging from about 7,250 to 9,800 feet. Greatest concentration is in the inter-Andean or valley areas, the outer slopes being very thinly settled in most places. The people are chiefly Indians, Spanish-Indians and Spanish. Most of the farm labor is performed by Indians and mixed Indian and Spanish. The purer Spanish are the land owners. Most of them dwell in the cities.

Dwellings.—Rural dwellings for the most part consist of tile-roofed houses, whose walls are made of large sun-dried brick or blocks of semi-consolidated volcanic ash material known as *congagua.* Similar buildings are plentiful in the cities as well. At the higher elevations one sometimes sees hut dwellings built of straw or páramo grass, and others covered with these materials but having mud and stick or *congagua* block walls. The bamboo and palm-thatched dwellings perched upon posts which are so characteristic of the Pacific Lowlands, are rarely seen above the middle western slopes of the Andes.

Soils.—The greater part of the Andean Highlands is deeply covered with volcanic ejecta, consisting of very fine to coarse ash material of a highly pumiceous character. In the substrata some feeble consolidation has come about at varying depths, apparently in beds where partial decomposition has taken place. Some of the more resistant of these *congagua* beds is mined in blocks, which are used in the construction of the walls of houses and field enclosures.

Much of the subsoil material consists of light-colored unconsolidated pumice fragments; the top soil everywhere is of a decidedly friable character, in places so loose as to drift in the wind. Organic matter from vegetation has darkened the surface material, giving rise to brown and black soils in the more humid localities, these extending from the valley floors up the slopes to the upper limits of the páramos. In the drier sections the soils are lighter colored, often gray and even whitish in those places where a flour like fine ash known as *puschig* is abundant. Lime carbonate has accumulated in the substrata of the more arid sections, but not to the degree characterizing the Great Plains region of the United States.

The common podzol soils of northern North America, Europe, and Asia was not found. Their absence may be due to the existence of such conditions as a periodic dry season, the absence of trees, and the rather mildly acid character of the soil-forming material.

Texturally, the soils consist mainly of sandy loam and loam. There probably are heavier textured soils in the southern extension of the Andes, where there is less volcanic ash and much more soil which has

been formed through the decay of the underlying rocks. The content of organic matter is generally good, except in the long-used, light-colored sandy lands, such as those covering the valley floor north of Quito.

In general the soils are productive; but many fields have been continuously cropped without sufficient rotation for the maintenance of the most favorable soil condition. Usually the yields are good where water is available for irrigation, and light in the older, sloping fields where irrigation is not practiced.

Vegetation.—The inter-Andean region is sharply differentiated from other parts of the country in its vegetation. Less distinctiveness in this respect exists in the humid forested portions of the lower outer slopes, where the Andean flora merges with that of the lowlands to the east and west. In addition to its general regional distinctiveness, the flora of the higher Andean country shows marked contrasts from place to place, as determined chiefly by temperature and rainfall. Wolf describes a number of vegetative variations corresponding to soil differences.[5]

The most conspicuous types of vegetation are: (1) The bush type of the humid areas, extending up to the high grasslands; (2) the high grasslands or páramos; (3) the dry land type; and (4) the forests of the outer humid slopes.

Entering the interior or Andean trough region, one is struck by the absence of natural forests. Broad areas of valley land and mountain slope sweep before the eye without a single patch of forest, save that of introduced planted trees. Not a tree, not a stump, not a vestige of buried log, indicating that forests formerly existed here, was seen. The centuries of occupation extending back beyond Incan time, with rural population and agriculture, largely concentrated within the region, could easily account for complete deforestation, although some evidence of former forests should have been left, it would seem, if they ever existed here.

There appears to be no good reason why trees should not have grown naturally in such situations as the valleys about Quito, where the annual precipitation is 44 inches and the mean temperature 55° F., unless the growth was prevented by repeated falls of volcanic material.

The bush type of vegetation, the *bosquecillos* (little woods), reaches up to an average elevation of approximately 11,500 feet. This probably covered, also, the valley floors before they were cleared. This zone includes a large variety of plants, few of which exceed 15 feet in height.

[5] Geografia y Geologia del Ecuador, Wolf, Teodoro, pp. 441-450.

They occur in mixed growth, except for occasional pure stands of St. John's wort along the upper margin. Constant changes take place in the plant formation with increase in elevation, some plants disappearing and others coming in. Some of the more conspicuous plants are fuschia, broom, *chilcas* (*Baccharis* sp. and *Eupatorium* sp.), St. John's wort, alder, a rather tall shrub known as *calka,* and a small scraggly bush producing an edible fruit known as *guagua manzana.* Lupine, small bamboo, and *sigsig* (*Arundo nitida*) are farliy common.[6]

The higher bush lands are constantly being recleared for potatoes and barley. Along the lower slopes the land is almost completely in continuous cultivation, but the regional bush growth is to be seen along roadsides and in the quebradas.

The *páramos* are densely covered with a coarse bunch grass resembling the common wire grass of the yellow pine region in southeastern United States. It is known as *paja de páramo,* and affords grazing for horses and mules up to the region of thin soil and rock at about 14,500 feet. Frost and ice are of common occurrence at night, and strong cold winds often sweep over these areas. On sunny days when the wind is low the climate is always delightfully springlike, and dandelions, buttercups, and other low flowering plants sparkle over the lower areas. In the dry sections prickly pear and a variety of cacti, henequen, acacias, and other dry-land plants flourish over the lower flat areas. The steeper dry slopes support but scanty growth of vegetation, which affords some grazing for sheep and goats.

The drier parts of the outer slopes of the Andes are also of desert-like character in their vegetation, such as the country along the railroad above and below Huigra. Elsewhere, with heavier precipitation, forests ascend the outer slopes to an elevation of about 9,800 feet, or considerably above the lower floor of the treeless inter-Andean trough. This zone has been styled the *Montañas tropicales de los Andes,* but it is more temperate than tropical along its upper margin, where alder and blackberries are to be seen. The trees become increasingly smaller above an elevation of about six or seven thousand feet. A small tree zone representing a transitional plant formation between the true forest and the true bush zones is found at about 10,000 feet. This intermediate belt, known as the *ceja de los montaña* (eyebrow of the forest), includes some trees of 30 feet height, or large enough to be dignified by the name of tree rather than bush.

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[6] Wolf describes the botany of this and other Andean regions in detail. See Geografia y Geologia del Ecuador.

From these outer forests some wood for the manufacture of matches is carried out to Quito, and occasionally a little lumber for building is packed out by muleback from the upper forests.

Agriculture.—General farming and animal husbandry are the principal agricultural industries, with the growing of eucalyptus trees for lumber and fire wood as a very important adjunct. Farm work is done by native labor under the direction of overseers.

On these Andean farms the bulk of the food used in the highlands is produced, and there is a considerable surplus for the towns and cities of the Pacific Lowlands, with a small excess of lentils, beans, butter, and potatoes for export. The rural population, as well as a large proportion of the urban population, consumes little or nothing of imported food or clothing. Some bananas, plantains, cacao, rice, cotton and other lowland products are shipped or packed into the Andean Highlands from Pacific Ecuador. Woolen and cotton cloths of good quality are manufactured locally. Country women when not busy in the fields or with their house work spend much time spinning wool with a spinning needle carried about in the hands. They can be seen often busy with their little hand spinning outfits while walking along the trails and bypaths.

It is interesting to observe how nearly completely the available lands of the region are utilized for crop production, arboriculture, and the raising of live stock. The hillsides are crazy quilts of little fields, eucalyptus groves, and pastures. As stated, the sloping lands are well taken care of by terracing, and most of the water is saved for irrigation, at least, in the region north of Riobamba. Many miles of canals and tunnels have been constructed for distribution of irrigation water.

Crops are still being grown after centuries of cultivation, and the indications are the same fields will continue to be farmed indefinitely. Often the yields are low, partly because of inadequate moisture, and partly because of erosion and soil long-used without refreshment. The dark lands of richer humus content have endured so well that fair yields continue to be made without manure. Some soil improvement is effected through the growing of such soil-improving crops as alfalfa, beans, and the lupine called *choco* (*Lupinus cruckshanksii Hook*), and by periods of reversion to bush growth; but the area receiving such treatment is relatively small. Increased yields could be brought about generally by growing more of the soil-improving crops; but the necessity commonly felt for using the land continuously for food crops, wood, and livestock is likely to restrict soil improvement by the practice of crop rotations to narrow limits. No doubt good response would

come from the use of fertilizers; indeed this has been proved in the case of nitrate salts which have been collected from the environs of the ancient dryland city of Latacunga.

Since most of the arable land and available water supply are in use there seem no means of largely increasing the agricultural output of the Andean Highlands of Ecuador, except by the use of fertilizer or by a combination of fertilizers and the growing of soil-improving crops. It is not likely that in this region any considerable increase of production will come in the near future. The unused areas of the Pacific Lowlands and of the untouched *Oriente* must be drawn upon to bring about any large increase in the production of agricultural products.

Conclusion.—The present indications are that increased prosperity of Ecuador will depend in a large degree upon increased agricultural production, including extensive development of new crop industries, such possibly as bananas, henequen, and Para rubber.

There is very little room for increase in the producing area of the Andean Highlands. Some increase of production could be derived from more extensive use of fertilizers and soil enrichment by a more general practice of crop rotations; but additions to the crop yields by these methods, if realized at all, will come slowly.

Eastern Ecuador includes large areas of fertile land of favorable topographic features, but this in the absence of easy means of transportation is a remote country. Any real improvement of transportation conditions in that region will require the building of difficult and expensive highways and railroads.

For the geographic causes described the fertile lands along the western base of the Andes and elsewhere in the Pacific Lowlands hold out the most promising opportunities for immediately increasing crop production on a large scale.

DETAILED FIELD MAPPING IN THE STUDY OF THE ECONOMIC GEOGRAPHY OF AN AGRICULTURAL AREA*

By WELLINGTON D. JONES and V. C. FINCH

Sound conclusions in geography, as in any other subject, must be based on facts. A large proportion of the facts needed by the geographer can be obtained only in the field, and since observations of workers in other sciences and of untrained travelers have proved quite inadequate for the geographer it is clear the latter must make and record his own fundamental observations as a basis for description and interpretation. Field maps constitute a vital part of the record of these observations, and a problem of primary importance therefore is the determination of what observed facts shall be mapped and how the mapping shall be done.

Recently a group of geographers met in the field to consider this problem of mapping, in so far as it is involved in the study of a region dominantly agricultural. It was agreed that the objective of an economic geographic study of a region is the determination of relations between its economic life and its natural environment.

It was further agreed that sound generalizations about a region should be based on intensive studies of typical small areas. The considerations set forth in this paper deal with the field mapping which is essential in such intensive studies.

Three propositions were considered as to the type of maps to make; (1) five or more separate maps showing (*a*) land utilization, and (*b*) such facts of the natural environment as slope, soil, drainage, and natural vegetation; (2) two maps, one of land utilization and one of natural environment (the combination of such facts as slope, soil, drainage, and natural vegetation); (3) one map combining land utilization and natural environment, this map being in effect a synthesis of the several maps noted in the first proposition.

The five separate maps of land utilization, slope, soil, drainage, and natural vegetation, if properly made, are of exceedingly great value in a study of the economic geography of an agricultural area. The chief problem in making these maps is in each case the recognition of types worthy of differentiation.

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* The suggestions made in this paper are the joint conclusions of a group composed of Charles C. Colby, D. H. Davis, V. C. Finch, William H. Haas, Wellington D. Jones, A. K. Lobeck, Kenneth C. McMurry, A. E. Parkins, Robert S. Platt, and Derwent S. Whittlesey. This group met for conferences on geographic field mapping in May 1924, at Bagley, Wisconsin, and in May 1925, at Hennepin, Illinois.

The following major types of land utilization were recognized in the areas studied by the group whose conclusions are reported in this paper:

(a) Tilled land, differentiated into types on the basis of crop combinations;
(b) Grass lands, used for pasture or wild hay;
(c) Wooded land, differentiated into types on the basis of utility;
(d) Idle land;
(e) Settlements, both towns and villages and separate farm-steads;
(f) Permanent streams and lakes, not navigable waterways;
(g) Navigable waterways;
(h) Land transportation routes, railroads and roads, with a differentiation between roads good all year and good at certain seasons only.

For slope it seemed desirable to distinguish at least three types, each enough different from the others in possibilities of use to warrant differentiation:

(a) Slope so slight as to lead to no undesirable soil wash and not to interfere with the use of machinery in cultivation;
(b) Slope great enough to be likely to lead to undesirable soil wash except in the case of very permeable soils and to interfere with the effective use of machinery in cultivation;
(c) Slope so great as to preclude continuous cultivation except by terracing.

As to soils, the group making this study did not come to anything like a final classification which would clearly differentiate soils into types differing in utilization possibilities. It seems as though not only surface soils must be taken into account, but the entire soil profile to a depth of several feet. Study on a classification of soil profiles suitable for the use of geographers is urgently needed.

On the basis of drainage, land may be classed as inadequate, satisfactory, and excessive. Drainage is a resultant of slope, soil profile, climate and vegetation, but this resultant is observable and for most areas its recognition seems worth while.

Natural vegetation in any given area can without great difficulty be classified, on the basis of characteristics which bear on use and landscape aspect, into well defined types.

The scheme of making two maps, one of land utilization and one of natural environment, in the place of five just described, has certain distinct advantages. In the first place, it greatly simplifies field procedure, it being easier to carry on work on two rather than on five

sheets. In the second place, it combines in a useful manner the outstanding facts of the natural environment as they are combined in nature. The procedure is to mark off on the one map areas which are essentially uniform throughout in utilization, and on the other map areas possessing essential uniformity in their *combination* of slope, soil, drainage, and natural vegetation (where the latter exists), and to set down in the notebook a detailed description of each type of area. It seems likely that comparison of the land utilization map with a map of natural environment will prove more productive of significant conclusions than comparison of the land utilization map with separate maps of slope, soil, drainage, and natural vegetation.

The idea of making a single field map that combines observed facts of land utilization and of natural environment grew out of the making of the two maps described in preceding paragraphs. Such a map was made in the Hennepin (Illinois) area and is here presented for consideration. As far as the routine of mapping is concerned, it is simpler to make one map than to make two or more. In directing attention to what is significant, the making of this single synthetic map offers peculiarly promising possibilities. The procedure in the field is as follows. A given spot is observed, as to utilization and as to the complex of natural conditions there existing. A note is made of these facts and of the known or probable relations between them. The area within which these facts of use and environment are essentially uniform is then outlined on the map. Adjacent but different areas are similarly distinguished, described in the notes and outlined on the map. Presently certain types of land are found to recur within a district, and to be typical of the region of which the district is a part. If an area marked off on the map is uniform throughout in land utilization and in natural environment it would seem to follow that it is uniform throughout in the relation between these two sets of facts, and experience in the Hennepin district bears out this conclusion. The single field map just described thus becomes in effect one showing types of areas according to fundamental geographic relationships.

On the field map of a small area some four or five miles northeast of Hennepin, Illinois, (Fig. 1 is a reproduction of this in line drawing) colors were used to show major types of land utilization. At a glance one can determine from the map the distribution of tilled land (yellow), grassland used for pasture or wild hay (orange), wooded land (green), idle land (gray), farmsteads (pink), roads and railroads (black), and water areas (blue). Closer scrutiny of the map shows that the tilled areas, the grass areas, and the wooded areas are subdivided and num-

bered. Each of these numbers distinguishes a type of area that is different from the others in the complex of observed facts of land utilization and natural environment. Brief descriptions of each type are to be found in the legend accompanying the map, these descriptions set forth the outstanding characteristics of each type of area, and serve as a condensed but clear and effective characterization of the variety of conditions which exist in the district mapped.

In distinguishing these types of land in the field it is well to differentiate more rather than fewer types. As field work progresses, and in final working up of conclusions for publication, it is possible to combine types which seem on more mature consideration to be so much alike as not to warrant differentiation.

The scale of the field map should in most cases be at least four inches to the mile, in order that all the details required can be entered without crowding.

Such a map can be made in the field note book, employing a compass for reading bearings, pacing for determining distances, and a ruler protractor for plotting bearings and distances. A small portable plane table and a ruler alidade, however, greatly facilitate the work of mapping. The use of colored pencils in the field is not essential, although many workers prefer to use them. Good topographic maps, post road maps published by the Post Office Department, plat book maps showing land ownership, and various other maps are useful where available.

Before maps of the type described in this paper are made, a reconnoissance of the region under study should be made to determine which small typical areas to map in detail.

The chief justification for detailed mapping of small areas is that it helps greatly in accumulating the facts which serve as the basis of sound, broad generalizations with reference to regions, which generalizations constitute the ultimate goal in geographic study. The making of one map showing *types of land according to the combined facts of use and natural conditions* compels the observer to group together in the field phenomena which occur together and thus is much superior to synthesis in the office of related facts. For publication purposes the single map perhaps will not entirely take the place of the several separate maps described earlier in this paper, but they can be constructed in the office as necessary from the one field map.

The problem of determining what facts are significant in a given area still needs to be worked on. It calls for the most careful consideration by all geographers. The problem varies with the area, whether rural or urban, middle latitude or low latitude, arid or humid, plain or

mountain, newly settled and undeveloped or long populated and highly developed—it is as wide as the world and as multiform as regions are in inhabitants and in natural environment. The tentative suggestions made in this paper are put forward in the hope of stimulating active research along these lines by geographers everywhere.

The opinion has been expressed that the making of a single field map, combining land utilization and natural environment rather than two maps, one of land utilization and one of the natural environment, may lead the observer to overlook significant facts either of land utilization or of natural environment. Certainly, the greater the variety of elements handled in a synthesis, the greater the difficulty of combination. On the other hand, synthesis is essential in geographic study, and the single map compels synthesis. Whether or not the method suggested in this paper will work can be determined only by its repeated application in the field. It will stand only if it proves its worth in actual use.

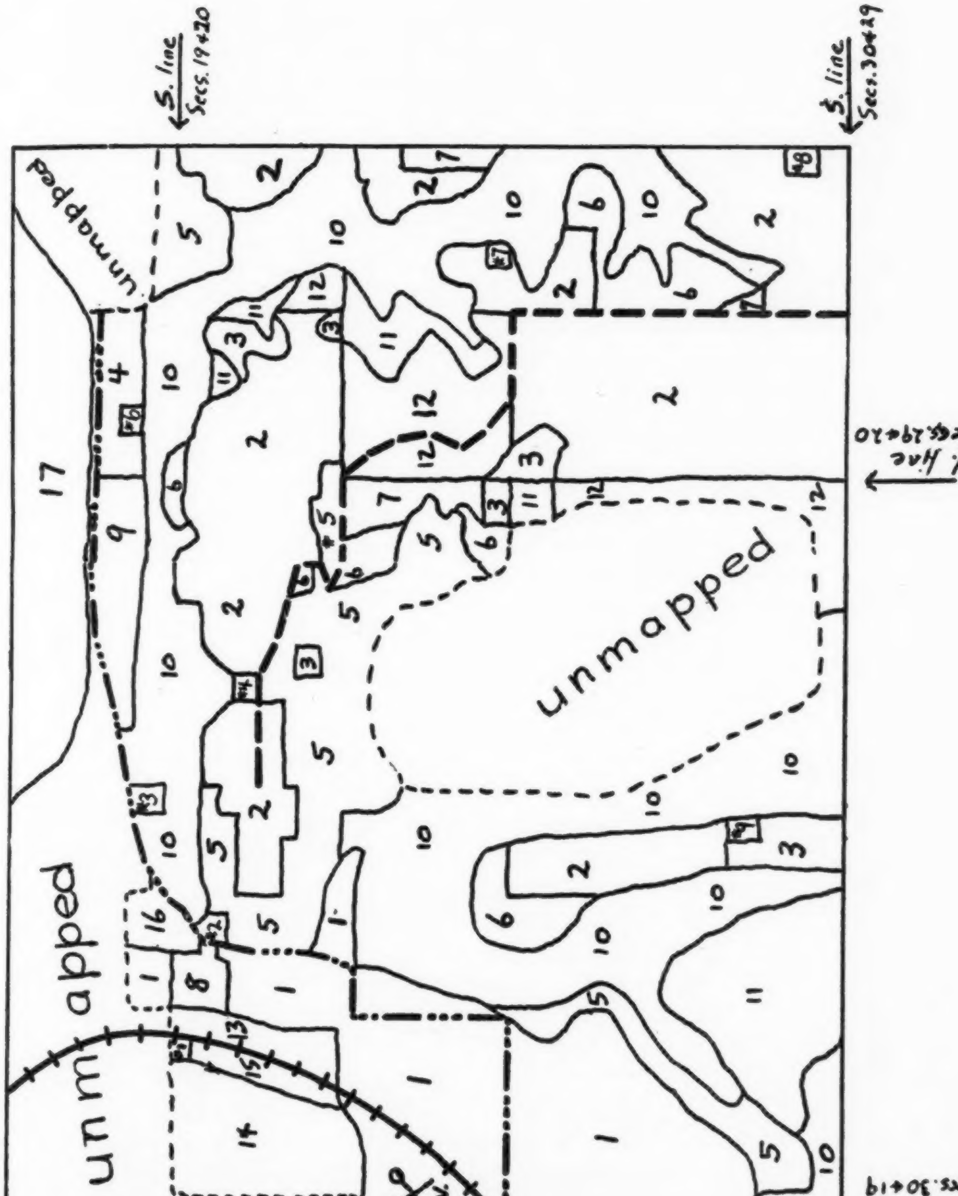

Fig. 1 Types of Land near Hennepin, Illinois, differentiated according to observed facts of land utilization and natural environment. Scale four inches to one mile. The map covers all of section 30, 4½ miles northeast of Hennepin, and parts of sections 19, 20, and 29.

The area can readily be located on the Hennepin topographic sheet of the United States Geological Survey.

The types numbered and described below and shown on the map opposite, were established in a two days' field trial of the proposed method of mapping, but more study is necessary firmly to establish the validity of these types. The map should be colored as directed in order that major types of land utilization show clearly:

A. Tilled Land (yellow).

1. Slope and topographic location—flat; valley bottom.
   Soil—silt loam surface soil, low in humus; sub-soil not examined.
   Drainage—good, except in very rainy weather; water table fairly close to surface, so that in dry weather this type of land does not get so dry as to injure crops seriously.
   Vegetation—originally forested; maple, elm, oak; valley floor type.
   Use—tilled, chiefly for corn; excellent crops, suffering occasionally from wetness.

2. Slope and topographic location—flat; upland.
   Soil—silt loam surface soil, low in humus; sub-soil, at a depth of a few feet, clay.
   Drainage—good; in rainy weather this land may get too wet; in dry weather it is likely to get too dry because of rapid run-off into bordering ravines and because of low water table.
   Vegetation—originally oak forest; upland type.
   Use—tilled; corn, oats, hay in rotation; excellent crops, not so good as No. 1 in dry seasons.

3. Similar to No. 2 except in the following respects:
   Slope and topographic location—slope great enough to lead to some soil wash and to impede somewhat the effective use of machinery; upland slopes to bordering ravines.
   Soil—clay loam.
   Drainage—so rapid that the fields almost never are too wet, and they dry out at times even more than those on No. 2 type.
   Use—similar to that of No. 2, but yields are somewhat less and fields deteriorate somewhat from wash.

4. Surface and topographic location—slope steep enough to lead to some soil wash and to impede somewhat the use of machinery; lower bluff slopes.

Soil—clay loam, stony in places; sub-soil clay.
Drainage—good, with water table close enough to surface to prevent serious drying out in droughty weather.
Vegetation—originally oak forest; slope type.
Use—tilled; corn, oats, hay; in quality between No. 2 and No. 3.

B. Grass Land, for Pasture or Marsh Hay (orange)

5. Slope and topographic location—slope so steep as to be unsuited to ordinary tillage; bluff slopes, valley sides, ravine heads.
Soil—clay loam, gravelly in places; sub-soil clay.
Drainage—good to excessive.
Vegetation—rather a dry type of grass sod; in places scattered trees, mostly oak.
Use—fair pasture, with some slight use as woodlot.

6. Slope and topographic location
Soil   Similar to No. 3
Drainage
Vegetation—good grass sod, with scattered trees, mostly oak.
Use—good pasture, with some slight use as woodlot; potential tilled land similar to No. 3.

7. Slope and topographic location
Soil   Similar to No. 2
Drainage
Vegetation—good grass sod, with scattered trees, mostly oak.
Use—good pasture, with some slight use as woodlot; does not dry out as much as No. 5 or No. 6; potential tilled land similar to No. 2.

8. Slope and topographic location
Soil   Similar to No. 1
Drainage
Vegetation—good grass sod.
Use—good pasture; does not dry out as much as No. 5 or No. 6, or even No. 7; potential tilled land similar to No. 1.

9. Slope and topographic location
Soil   Similar to No. 4
Drainage
Vegetation—good grass sod and scattered trees, mostly oak.
Use—good pasture.

C. Wooded Land (green)

10. Slope and topographic location
Soil
Drainage
Similar to No. 5
Vegetation—oak forest, mostly second growth; slope type.
Use—woodlot and summer pasture.

11. Slope and topographic location
Soil
Drainage
Similar to No. 3 and No. 6
Vegetation—oak forest, mostly second growth; upland type.
Use—woodlot and summer pasture; potential tilled land similar to No. 3.

12. Slope and topographic location
Soil
Drainage
Similar to No. 2
Vegetation—oak forest, mostly second growth; upland type.
Use—woodlot and summer pasture; potential tilled land similar to No. 2.

13. Slope and topographic location
Soil
Drainage
Similar to No. 1
Vegetation—forest of valley floor type; maple, elm, oak.
Use—woodlot and summer pasture; potential tilled land similar to No. 1.

14. Slope and topographic location—flat; high valley terrace of Illinois Valley.
Soil—dark silt loam; sub-soil at a depth of 3 feet, glacial outwash sand and gravel.
Drainage—good.
Vegetation—forest.
Use—timber and woodlot; potential tilled land of fairly good quality.

15. Slope and topographic location—steep slope from terrace to valley bottom.
Soil—Sandy, gravelly loam.
Drainage—good.
Vegetation—forest.
Use—woodlot.

D. Idle land (gray)

16. Slope and topographic location—flat; valley floor.
Soil—peaty.
Drainage—poor; under water all year.
Vegetation—cattail marsh.
Use—waste; perhaps potential tilled land if drained.

E. Water (light blue)

17. Shallow bayou of the Illinois River; perhaps potential tilled land if drained.

F. Farmsteads (pink)

Each farmstead is given an identifying number, and is described in detail in the notebook, as to character of buildings, numbers of animals, orchards and gardens, and a variety of other significant facts.

G. Roads and Railroads

Two types of roads are shown, those good except in wet weather (dashes), and those poor at all times (dashes and dots). A third type, good in all weather, does not occur in this area. The conventional symbol is used for railroads.